

**The Association
of
Engineering and Shipbuilding
Draughtsmen.**

CASTINGS.

By A. K. HAMILTON.

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SESSION 1948-49.

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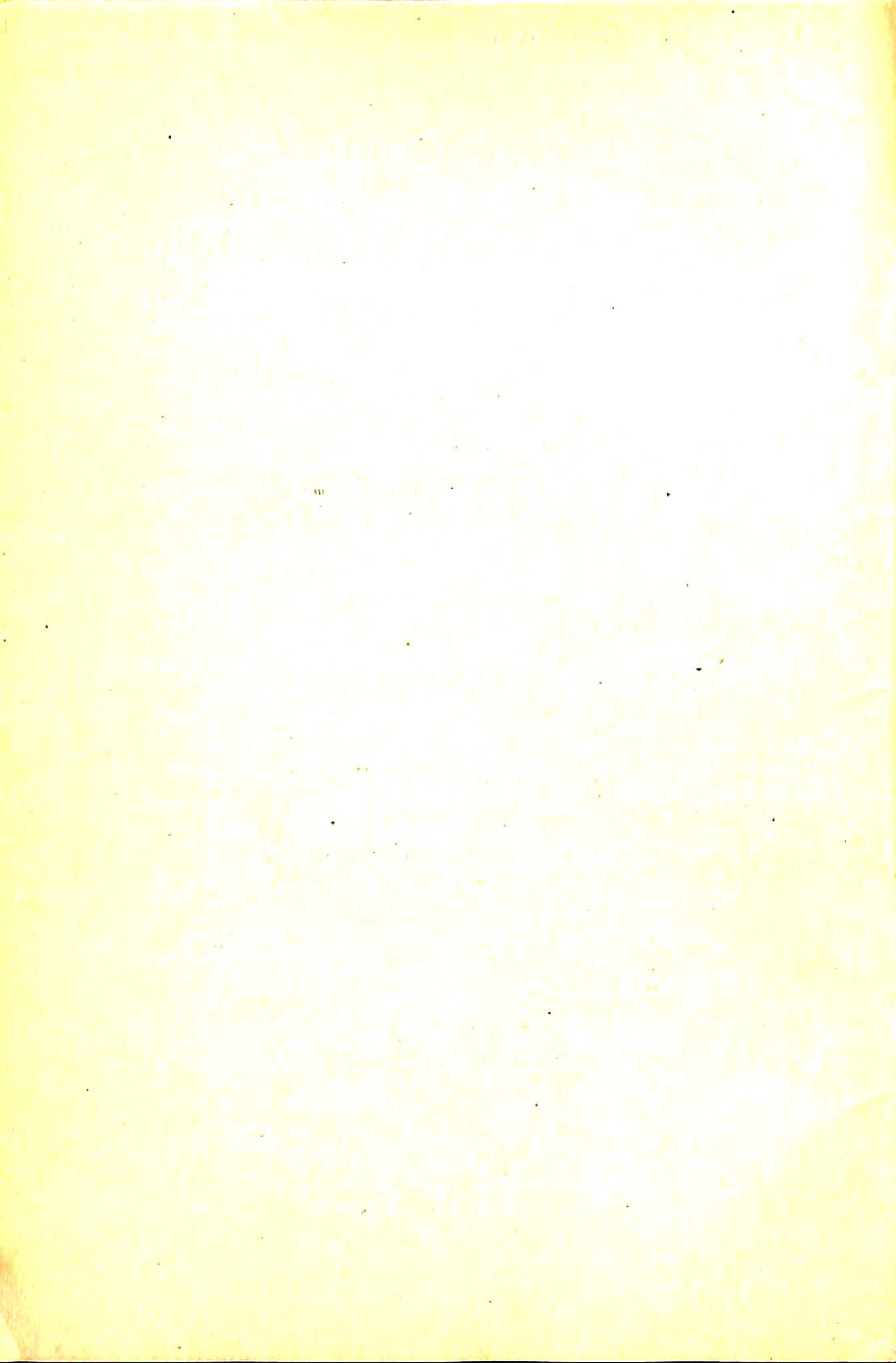
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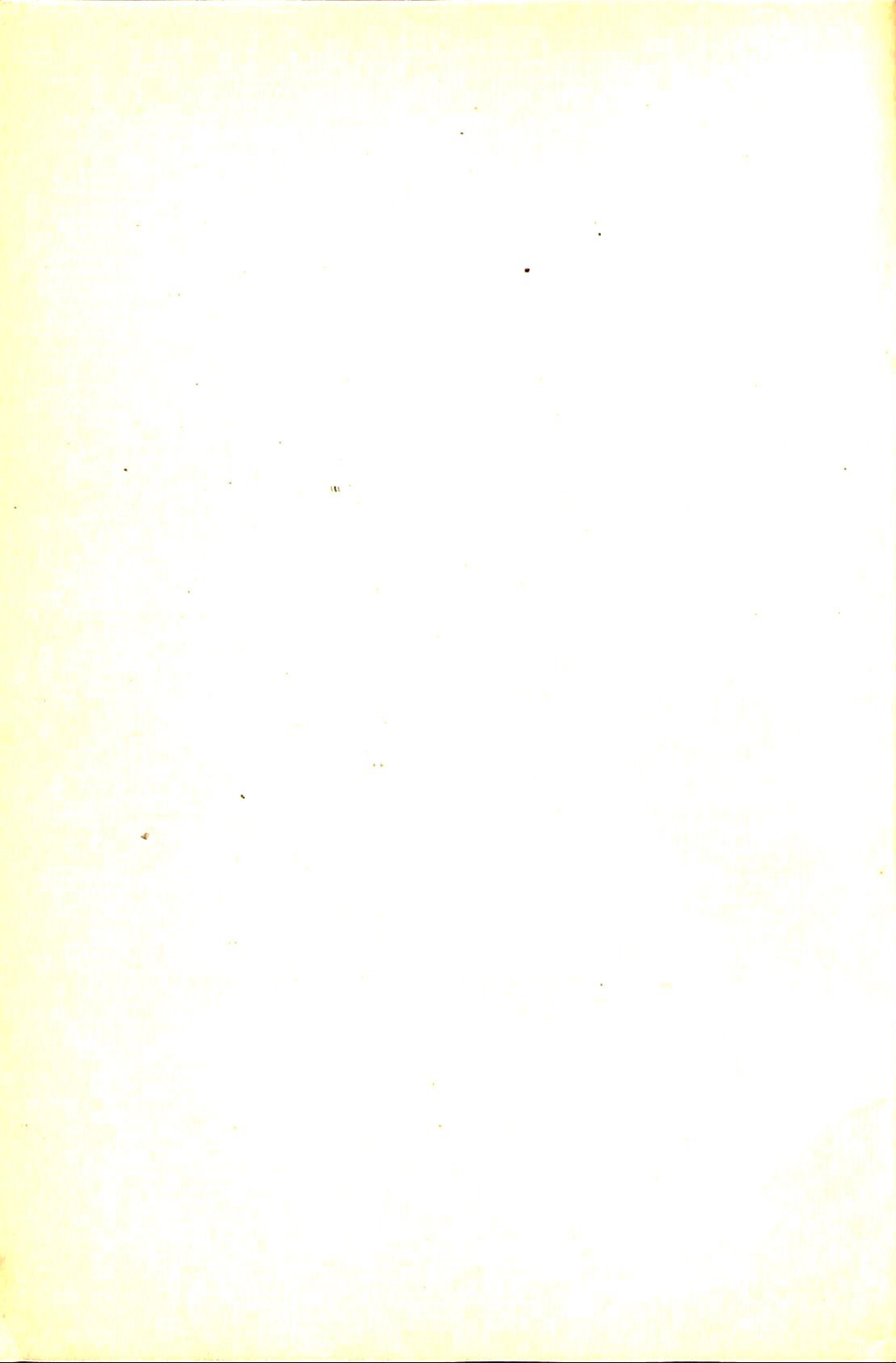
PREFACE.

FULL advantage of the unique properties of castings can only be obtained if there is close co-operation between the designers and manufacturers of these important commodities, and there is no doubt that personal contact between those concerned is the best method of obtaining this.

Many draughtsmen, however, are employed in establishments not directly connected with foundries, so that there is little opportunity for practical training or joint consultation, and in consequence, as may well be expected, the foundry aspect of any problem is seldom fully appreciated.

It is hoped, therefore, that a simple presentation of the fundamentals of casting production will help to bridge the gap in such cases and also encourage a greater consideration of foundry practice in its relation to design.

Space will permit only the general methods of procedure to be dealt with, but as these are responsible for the output of the great bulk of industrial castings, and are the basis of all others, it is felt that they will suffice, or at least serve as a preliminary to the study of more specialised practices, if that is desired.



CASTINGS.

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INTRODUCTION.

Founding is the art of pouring molten metal into suitable moulds and allowing it to solidify therein.

The casting of metals has been practiced for over 5000 years by generations of craftsmen who inherited the skill and slowly enlarged on the empirical rules of their immediate predecessors, but it is only in this century that steps have been taken to reduce founding from an industrial art to an exact science.

The methods of the hand moulder have changed but little; it is in the control of the metal to be cast and the mould materials, that the most noticeable advances have been made.

The "suitable moulds" mentioned above impart their shape to the solidifying metal and the properties of the newly-formed casting are also, to a certain extent, influenced by the character of the parent mould.

The moulds may be fashioned in sand, in which case they are destroyed in the making of the casting; or they may be permanent, *i.e.* dies, and produce hundreds or thousands of castings before their replacement becomes necessary.

Despite the development of the die process for an increasing range of metals, by far the greatest weight of castings is produced from sand moulds, so it is with these that we will be mainly concerned.

To form a sand mould into the required shape, a former or pattern is necessary, and although in some cases the pattern may be an exact model of the object to be cast, more frequently it has to be specially constructed to facilitate the moulding process.

For this reason, if no other, patternmaking is a highly skilled and specialised trade, and as the first step in the production of a casting is the preparation of a pattern, it would be logical to consider this craft first. Patternmaking, however, is only a means towards an end, and as its principles are determined by moulding practice, it will be more convenient to make a prior examination of the art of moulding and its attendant trade, coremaking.

MOULDING.

Where or when the first mould was used is not likely to be determined, but it is fairly certain that the early founders used simple cavities carved in the ground adjacent to or directly below the smelting fires. Investigations have shown that in the period 4000 B.C., clay moulds were used for the casting of copper weapons, while 2000 years later, the Chinese, reputedly the first to cast iron, used stone moulds for this purpose.

Sand moulding from wooden patterns as we know it to-day was developed at the beginning of the 18th century and had its simplest form in the open top mould.

Although still used, the open mould is limited to castings having at least one flat side and owing to the pronounced meniscus of molten metal, the top edges of the casting would be decidedly rounded. With other than thin castings, another disadvantage in the shape of a shrinkage cavity will appear on the surface of the open mould product. This is due to cooling and solidification taking place progressively from the bottom upwards and the sides inwards, leaving the last liquid metal in the top centre.

As the temperature falls and liquid contraction takes place in the lower region of the mould, the upper metal is displaced downward but the fall in level is not uniform across the width of the casting as the outer skin of the metal, in contact with the cold mould, has already solidified at the original height of the cast. The depression, therefore, becomes progressively deeper towards the centre, and the defect becomes very apparent in deep castings such as steels ingots which are cast on end in moulds several feet deep.

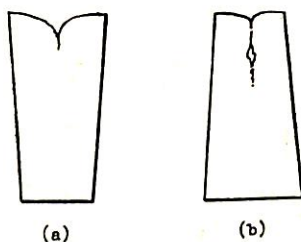


Fig. 1.

Fig. 1 (a) shows a vertical cross section through such an ingot with a typical shrinkage depression for that shape of mould, but if the upper surface should solidify before the internal metal, as is quite likely to happen if the mould is tapered in the reverse direction, as Fig. 1 (b), a cavity such as is indicated would be formed.

Open moulds either of sand or metal are invariably used for the casting of pig iron from the blast furnace; the shape of the resultant pig is unimportant as it has to be remelted for final use. Odd castings required for internal use in the foundry, rough plates, solid weights, etc., are frequently cast in open moulds, as these are easily made in sand and require a minimum of pattern and moulding equipment.

Where a sharp-edged level top surface is required on the casting it is necessary to have a head of metal to break the natural surface tension so that the corners of the mould may be filled, and a reservoir of molten metal at a higher level must be provided to make up for liquid shrinkage as it takes place. If fluid metal is used, it is easy to obtain a sharp impression of the mould, but very careful consideration is needed in many cases to produce a casting free from the effects of liquid shrinkage.

To provide these conditions a levelled-off bed of sand contained within a suitable supporting frame is placed over the open mould and firmly located. A hole through this layer of sand will allow for the entry of the molten metal while a second hole, conveniently placed, will allow the free exit of air and gases until the appearance of molten metal indicates that the mould is full. The mould is now under a pressure of metal determined by the depth of the top sand and if the outlet hole is correctly placed and dimensioned, the metal within it will compensate for liquid contraction.

For this riser or feeder, as it is known, to function satisfactorily, solidification must commence in the remote portions of the casting and advance progressively nearer leaving the last fluid metal in the base of the feeder itself.

The pouring hole known as the downgate or sprue is kept reasonably small, as it is essential, that once pouring has commenced, it is kept full of metal and for this reason it is seldom large enough to remain liquid after the remainder of the casting has solidified, so is thus not effective as a "feeder," though it does impart hydrostatic pressure to the mould.

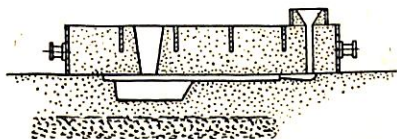


Fig. 2.

This arrangement of mould, as shown in Fig. 2, is typical of that used for the production of many large castings; the lower portion of the mould called the drag is formed in the floor of the moulding shop and the top section or cope is positioned over it by means of bolts or pegs and weights.

Smaller castings are more conveniently made if both portions of the mould are movable, so whenever possible, the drag mould is also made up in a frame independent of the shop floor.

This latter arrangement is that by which the great majority of castings are made and is essentially two separate frames of sand which dowel together to enclose a complete impression of the pattern, but which can be parted at will as is necessary during the moulding operations. Such a pair of frames is known as a moulding box or flask and Fig. 3 shows a typical box as used in graduated sizes up to approximately 24" $\times$ 18".

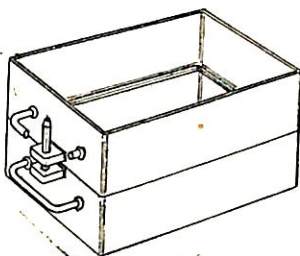


Fig. 5.

The flasks, which may be made of cast iron, mild steel or even wood, are provided with lifting handles and dowels or pins to locate the two halves accurately together. The pins are made several inches long to ensure that at the commencement of separation one box is steadied and guided vertically away from the other. Boxes larger than that illustrated have provision for lifting and turning over by cranes, and normally have ribs across their outer faces to support the larger areas of sand involved. In the bottom or drag box the bars are placed on the flat as they can support the sand from underneath, but in the cope box the ribs must be placed vertically and are taken as far into the flask as possible to obtain the maximum grip on the sand. In some cases, to increase their effectiveness, the ribs are shaped to follow at a slight distance the contour of a pattern frequently used.

Foundries carry a wide range of moulding boxes to deal with the general range of castings to be produced, but as these boxes represent considerable capital expenditure and require large storage space the number must be kept to a minimum.

A reduction in the quantity of boxes required by foundries making small castings may be obtained by the use of snap flasks.

The flasks are used and function as ordinary moulding boxes, but they are hinged at one corner so that when the mould has been completed and placed on the floor or conveyor ready for casting the flask may be opened and removed. By this means any number of moulds may be made with the one flask where otherwise a con-

siderable number of boxes would be held in use until the pouring and knocking out of the castings.

The snap flask moulds do not have to be entirely self-supporting, as it is usual to have metal bands, which, sliding neatly within the flask before the sand is added, remain with the latter and reinforce it when the flask is removed.

In large-scale repetition work it is often an economical proposition to make special moulding boxes, tailored as it were to suit a particular casting and its appendages. The box may, therefore, be of quite an unusual shape, but the reduction in the volume of sand required per mould and the gain in mould efficiency may make the preparation of non-standard boxes well worth while.

Moulding Sand.

In advancing a stage from the open mould, it becomes increasingly apparent that special properties are required of the sand used and that the ordinary sea-shore variety on its own is of no use. The requirements are listed below in the order in which they come into play in the process of producing a casting.

- (a) *Plasticity or Flowability.* The sand must flow readily to conform to the shape of the pattern under the action of squeezing or light ramming and still retain its cohesion.
- (b) *Green Strength.* In the damp or "green" state, as used for moulding, the sand must retain its shape after the pattern has been removed and must resist the eroding action of the molten metal during casting.
- (c) *Dry Strength.* If dried before or during casting, the sand must maintain its shape and possess reasonable strength.
- (d) *Permeability.* Gases generated during casting must be able to percolate freely through the body of the mould and so escape to atmosphere.
- (e) *Refractoriness.* The sand grains must be able to withstand the high temperatures encountered during casting.
- (f) *Fineness.* If a smooth skinned casting is to be produced, the sand grains must be reasonably small.

This stringent specification is difficult to attain in full, as some of the characteristics required conflict to a certain extent with others so that the sum of the properties obtained in practice is necessarily a compromise with the ideal. There are in this country, however, natural deposits of sand giving a wide range of moulding properties depending on the geographical area or geological age of the deposit from which they are obtained, and with the skilled selection of these, good sands can be provided for all classes of work.

The term natural sand here refers to those which have deposited with them in their natural state sufficient clay to provide

a reasonable bond. The collapse of the child's sand castle under the drying action of the sun is due to the lack of clay in sea sands.

A good moulding sand consists essentially of uniform grains of silica, coated with a thin film of bonding clay and containing from 3% to 7% of free moisture. The sand, as mined, must always be milled to distribute the clay evenly over the sand grains and water must be added to bring the moisture content to the desired figure. The siliceous nature and size of the sand grain determines its refractoriness, the uniformity and shape decides its permeability, the clay provides plasticity as well as green and dry strength while the moisture increases the flowing power, dry strength and up to a certain point the green strength.

Large variations in grain size, excess of clay or moisture will reduce the permeability of the sand as the interstices of the grains become filled and as clay is less resistant to heat than the grain it surrounds the refractoriness of the mould as a whole decreases with increasing clay content. The heat resisting qualities of a sand improve with increase in grain size, due to the higher volume to surface area ratio, so that the higher the casting temperature the larger the grain size normally used. A coarse sand, though ideal for the passage of gases, produces a casting with a rough skin, while the fine sand necessary for smooth skinned castings has low permeability and refractory values.

This particular difficulty is overcome to a certain extent in the foundry by using two types of sand to make up the mould. The first variety, known as facing sand, is made up of specially prepared fine materials and is placed thinly over the pattern at the commencement of moulding, so that it eventually forms the inside surface of the mould. The other type used to fill up the remainder of the moulding box is a plain and coarser variety commonly called backing or floor sand. When the casting is knocked out, the two sands are inseparably mixed so that fresh facing must be made up. The backing sand is used repeatedly, but due to its gradual breakdown into fine particles or silt and the reduction of its bonding power, a percentage of new sand must be systematically introduced.

In the mechanised foundry where the sand is delivered to the moulders from a central mixing plant, it is not convenient to use two grades of sand and one of average qualities has therefore to be prepared.

As the dry strength of a normal moulding sand is greater than the green strength, larger or more intricate castings can be made in dried moulds. The process may be merely a skin drying by portable heaters or the moulds may be placed in a stove for complete dehydration. Dried moulds are extensively used in the steel casting industry, but with advances in sand control, green moulds are becoming more and more widely used and the extra cost of mould drying is reserved for high quality or heavy castings.

By selecting a pure silica sand of the required characteristics and milling with it a high quality bonding clay, it is possible to obtain, within closely controlled limits, a moulding sand with properties approaching the ideal for the particular class of work. Such synthetic sands, as they are termed, are being used to an increasing extent, particularly in the steel casting and mechanised foundries, although their initial cost is higher than that of the naturally deposited sands.

Moulding Practice.

It is a general rule in moulding that the bulk, or all of the casting, should be moulded in the lower or drag box.

This ensures that most of the molten metal will be below the joint line so there is therefore less chance of a "run out" which would destroy the mould and be a possible source of danger. This procedure usually simplifies moulding so that it is normally carried out, irrespective of advantages in other directions.

Another accepted practice is that machined surfaces should, wherever possible, be cast face down on the assumption that sound metal is more likely to be required at a machined face than elsewhere in the casting. This does not mean that the upper portions of a casting are necessarily unsound, but due to the fact that impurities such as slag, dross or sand, likely on occasion to contaminate the molten metal, are lighter than the metal itself and therefore rise to the upper surfaces, the possibility of finding unsoundness is much less at the bottom of a casting. The results of any unrelieved liquid shrinkage, too, are most likely to occur in the higher regions.

The moulder must take these points, as well as the physical shape of the pattern, into consideration when deciding the best method of moulding, and where the joint or parting must come. A joint or parting is necessary, of course, in all but open sand moulds and must occur in the region of the largest cross section in any one direction so that the pattern may be withdrawn from the sand or the mould from the pattern.

With the simple bearing bracket, Fig. 4, there would be no hesitation in deciding to mould this pattern all in the drag box, with the flat back of the bracket forming the joint line between the boxes. Assuming that the holes shown would be machined from the solid, the pattern is an exact model of the drawing, excluding the holes, and the completed mould, Fig. 5, is obtained in the following manner :—

The pattern is laid with its back on a flat board slightly larger than the moulding box to be used, and the drag is inverted and placed over it; that is, with the jointing face of the box on the board. A layer of facing sand is riddled over the pattern, after

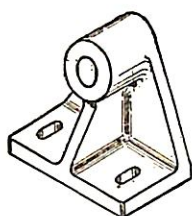


Fig. 4.

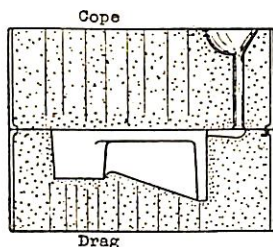


Fig. 5.

which backing sand is added progressively and rammed to the required compactness until the box is slightly more than full. The surplus sand is scraped or "strickled" off with a straight edge to give a level surface and before turning the mould over on to the floor or bench, the natural permeability of the sand is assisted by the thrusting of a fine wire several times through the mould towards the pattern.

The withdrawal of the wire leaves a series of vents which allow the ready exit of gases from the proximity of the mould face.

When the mould is turned over and the board removed, the inner joint with the back of the pattern flush with the sand is exposed, and the cope box is then placed in position.

Fine dry parting sand or powder is dusted over the joint surface to prevent the cope sand from adhering to that of the drag when it is rammed up in a similar manner. When the top box is filled and levelled off, a downgate is formed by thrusting a metal tube of suitable diameter down through the mould to the joint line, the core of sand within the tube being removed with the latter, leaving a smooth hole. Around the top of this hole a depression or basin is shaped to assist the entry of the metal at the time of casting.

After the use of the vent wire, the cope mould is lifted away, exposing the back of the pattern again, and assuming that the parting sand has served its purpose, an unbroken joint face will leave all in readiness for the removal of the pattern.

If this is a large one it should have let in on the upper face, a metal plate into which may be screwed, for lifting purposes, a long stemmed eyebolt, but sufficient grip may be obtained on small wooden patterns by tapping in a steel spike.

Before attempting to withdraw the pattern, the moulder frees it slightly from the clinging sand by jarring or rapping in sideways directions on a rod placed in a specially prepared and reinforced hole in the pattern. If no rapping hole is provided, the moulder will rap on the lifting screw or spike and this should be avoided, if possible, if the pattern is to be used repeatedly.

The removal of the pattern requires reasonable skill and care if it is to be accomplished without damage to the mould, and the advantages of a smooth well-tapered pattern will be obvious.

The final operation is to cut a channel or runner between the position of the downgate and the cavity left by the pattern for the entry of the metal. This runner may be a simple groove of suitable cross section or it may include special devices taking advantage of centrifugal or gravitational action to trap impurities before they enter the mould.

The cope box may now be replaced and to prevent the two halves of the mould being separated by the hydrostatic pressure of the metal during casting, it is necessary to weigh down or clamp the two boxes together, unless the casting is very small or has little area to develop an upward thrust of any magnitude.

Where a pattern such as the V-belt pulley blank, Fig. 6, has no flat back that can be placed on a moulding or turnover board, it is necessary to make what is termed an "oddside" to obtain the correct joint line.

For this the cope box is rammed up with sand and the pattern roughly bedded or pressed into it up to the required joint line; this then being more carefully shaped to the correct contour and finally dusted with parting sand.

The moulding now proceeds as before, the oddside mould taking the place of the flat board until the drag has been completed and the boxes turned over. When the oddside has been removed, the parting face of the drag mould is examined to check that it is at the correct level throughout and modified if necessary before the final cope mould is rammed up.

As it is not possible to obtain a uniformly compacted and accurately shaped mould by pressing the pattern into the sand by hand, the oddside is not suitable for use as the mould proper, and as it is knocked out after its initial use it is, in a sense, time wasted. Where a number of such castings is required, moulding time may be saved by the making up of a permanent or semi-permanent oddside in dried sand, plaster of Paris or other readily-formed substance, on which drag moulds may be repeatedly formed.

The preceding remarks are based on the assumption that the pattern is a solid one, for the use of specially jointed patterns eliminates the need for an oddside mould in most instances. In the case of the pulley, Fig. 6 (a), however, it is only necessary to recess the moulding board slightly to take the projecting top boss, for the pattern to be treated as a flat-backed one.

With the mould at the stage shown in Fig. 7, the next operation is to raise the cope for the extraction of the pattern, but it will be seen that this is more difficult than before as part of the pattern projects into the cope mould which will tend to break away along the lines indicated if the box is abruptly raised. Rapping, though

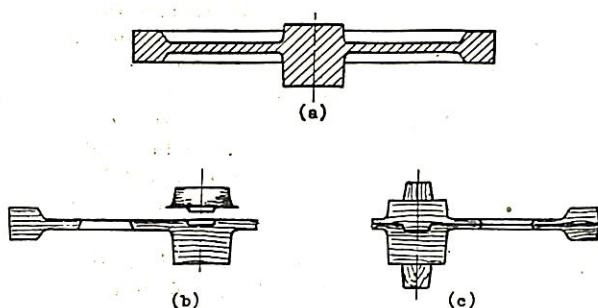


Fig. 6.

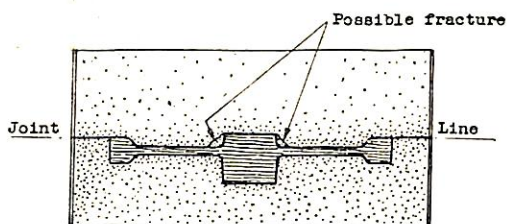


Fig. 7.

difficult to carry out successfully, will alleviate the trouble, but the best answer to the problem is to have the portion of the pattern embedded in the top mould free to lift away with the latter for removal at a later stage. The pattern is then constructed, as shown in Fig. 6 (b), which arrangement also enables the moulding to be started as with a flat back for the loose boss can be left off until the moulder is ready to ram up the cope.

When the cope mould is turned over, the loose boss is easily extracted, as it can then be lightly rapped and gravity assists to keep the mound intact. Where a solid pattern is being used, the moulder must place his rapping spike in position before completing the cope mould and later must rap on this spike where it extends through the sand.

As the point of application of his blows is several inches away from the pattern itself, the result of the rapping is never very definite until proved one way or the other by the opening of the mould. In such circumstances the rapping is likely to err on the side of being excessive to the detriment of pattern life and casting accuracy.

Unless used for the position of a riser or runner, the damage done to the mould by the rapping spike must, of course, be repaired.

Another way of jointing the pattern would be to make it in halves, as shown in Fig. 6 (c), the moulding joint would then be

the same as that of the pattern with half the casting in the drag and half in the cope. For hand-moulding, this arrangement shows no advantage over the loose boss pattern, but such construction is required for machine moulding where the patterns are mounted on plates.

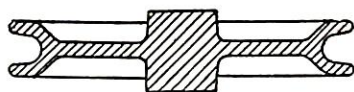


Fig. 8.

If a sheave pulley, such as Fig. 8, is to be cast with the groove formed by the green sand mould, the pattern must be split through the web and it is usual to mould this type of pattern in what are termed three-part boxes. As the name implies, the complete moulding box is in three parts, which mate together in a similar fashion to the two-part boxes.

The centre box is frequently shallower than the outer ones, but unless specially made, it seldom corresponds exactly with the requirements of the pattern, so that one parting face at least must be shaped away from the box edge.

Moulding commences with the making of an oddside in one of the outer boxes and then ramming up the mid-part box on this with the complete pattern in position, the sand being tucked firmly into the groove with the fingers. The oddside being removed, the drag and cope are made alternately on the middle part, completing the mould, as shown in Fig. 9. It should be noted that as the pulley edges are rounded, the parting line must run to the centre of the radius otherwise one of the mould edges will be pulled up when the pattern is removed.

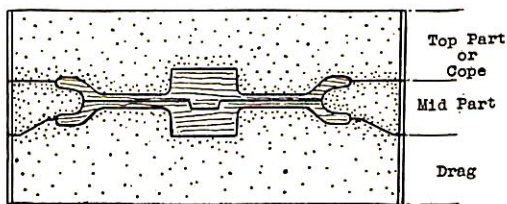


Fig. 9.

To extract the pattern, the top box is raised and the exposed half pattern withdrawn in the usual manner; the box is then replaced and the whole set up turned completely over for the other half pattern to be removed by the same procedure.

CORES.

The examples of moulding previously given cover the normal methods, but it will have been noticed in each case that the pattern was of simple outline and did not produce the holes normally expected in such castings.

It will be readily appreciated, however, that in a great many castings there are internal recesses, undercut portions or holes which cannot easily be formed by a pattern restricted in its shape by the fact that it must, as a whole or in parts, be withdrawn from the sand in which it is embedded.

These particular features are formed by baked sand impressions known as cores and they are also used on occasion where a portion of the mould would be too fragile in green sand or where an overall saving of time may be achieved by extra coremaking.

The core or cores, after stoving, are placed in the mould as the last operation before it is closed, and not only must they be located in the correct position but they must be maintained there against the pressure and floating action of the metal at the time of casting. To this end, special projections known as prints are formed on the pattern, the cavities they produce in the mould being filled by replica projections on the core. These extensions to the core proper, fitting into the main body of the mould, locate and support the former, and as they prevent the entry of metal into the recesses formed by the prints the presence of these should not be detected on the casting. A core print can only be placed where the core will cut through an external wall of the casting and if the design will not permit adequate location by means of prints, metal supports called chaplets must be used.

Chaplets must preserve sufficient strength for their purpose until the metal has commenced solidification and be such that they will weld into the casting to form a homogeneous whole.

As cores have to be handled for insertion in the mould and are often subjected to bending stresses during casting, greater strength than that given by green sand, or even dried sand of the usual clay bonded type, is usually required.

A high refractory value is also desirable, for in a good many cases the core is almost completely surrounded by molten metal and is thus subjected to severe temperature conditions.

For the same reason, *i.e.* enclosure by metal, good permeability is essential if the gases are to find their way out along the core and not through the metal.

Core sands in general, therefore, are made from rather coarse-grained sea or river sand, mixed with a special organic binder, the resultant mixture, after forming, being baked at a temperature of approximately 200°C. to develop its full strength.

As with moulding sands, there are many varieties of core sand and bonding mixtures giving a wide range of properties.

The binders may be made of drying oils such as linseed, molasses or similar carbohydrates, starchy substances obtained from cereals or members of the resin and gum families.

The most common core binders contain linseed oil, which has a very good dry strength when oxidised, with additions of other materials, such as the starchy compounds to improve the green strength, so that there is no likelihood of deformation before baking.

Other factors influencing the choice of a core bonder are its resistance to moisture, the amount and nature of gases evolved during casting and the rate at which it loses strength at temperatures above those of baking. This last point is important as the core should not resist the solid contraction of the metal, which at elevated temperatures, is weak and liable to fracture if restrained.

Core Making.

Core making is considered a separate trade in the foundry, one portion of which is usually set aside for the making and baking of cores.

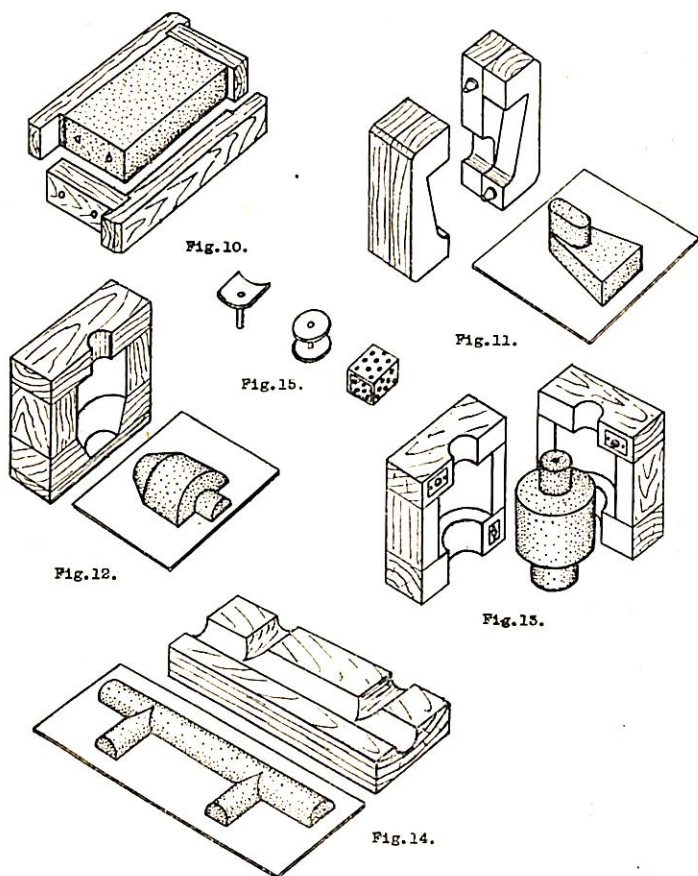
Plain cylindrical cores of standard diameters up to six inches are commonly extruded from a screw feed type of machine through changeable dies. These cores are baked in convenient lengths and cut up as required by the moulder.

Shaped or non-standard cores are made by ramming, pressing, jolting or blowing the sand mixture into specially made boxes which are in effect moulds for the core. The internal shape of the corebox must be that of the portion of the casting to be produced plus the extensions for the prints and the box must be jointed or so fashioned that it can be lifted away from the core, leaving the latter on a metal plate for insertion in the baking oven. At least one side of the box must be open for the ramming up of the core and if the open side is flat it serves conveniently for turning out the finished article on to the baking plate.

Figs. 10 to 14 illustrate the construction of simple core boxes and the method of leaving the core on a plate so that further handling in the green state is not necessary.

The halves of the boxes may be held together by clamps, screws or special clasps and they are rebated or dowed for exact location.

Patternmaking time is reduced and stoving simplified if symmetrical cores of some shapes are made in halves and pasted together after baking. Fig. 12 indicates such a half corebox and core, the two impressions of which can be baked resting on the flat jointing faces, an obviously more stable arrangement than that possible for the whole core, Fig. 13.



Shaped cores liable to distort or flatten in the green state must be supported during the baking process on a bed of dry sand or, if the quantity justifies it, on specially made solid formers. Such support is advisable where the round face of a core would otherwise bear on a flat plate, but here again the making of the core in halves, as in Fig. 14, may obviate the need for such precautions.

The coremaker is assisted mechanically by machines which consolidate the core by jolting, pressing or vibrating the mixture in the box, but quantity production of small cores is most rapidly increased by the use of blowing machines which, under the action of compressed air, inject a stream of sand at high velocity into the box. Metal coreboxes are needed with blowing machines to withstand the abrasive action of the sand and careful box design is also necessary, but given these, very efficient cores can be produced at a high rate of output.

Venting.

It is most important that the gas generated in or around the core during casting is able freely to escape to atmosphere through the core itself, for if this is not permitted the gas will endeavour to force its way through the metal, causing blow holes or porosity in the process.

In the correct manner the gas can only escape *via* the core prints and as the cross sectional area of these is limited, the natural permeability of the sand mixture is seldom sufficient to conduct away quickly the volume of gas accumulating from over the larger area of the core. Clear gas channels or vents must therefore be made to connect the outer faces of the prints with the interior of the core, the size and complexity of the vents varying with that of the core. Further, the moulder must see that the gases escaping from the core prints have an easy exit through the backing sand or the coremakers efforts will be nullified.

Small straightforward cores may be adequately vented by the thrusting of a wire or spike into the core from the print sections. This should be done before the core is turned out of its box so that if the prints are not to the open side of the box it is necessary to have holes in the sides for the application of the vent wire. An alternative to venting after ramming is to place the wires through the sides of the corebox during the forming process and withdraw them when it is completed.

An effective venting system is obtained by placing threads or strands of wax in suitable positions in the core as it is being made. The wax, which may be extruded in strings about $\frac{1}{16}$ " in diameter, or formed on threads of cotton, melts out during the baking process, leaving clear and uniform passages in the core. This type of venting is particularly advantageous where the core is of intricate shape, as the wax thread can be bent to follow any contour and joined up as required.

A further advantage of baking cores in halves is that vent-paths can be cut along the joint faces before the portions of the core are glued together, and providing that the channels are not filled with paste, the effectiveness of the venting is therefore not in doubt.

Steel tubes with their walls well perforated with holes may be inserted in larger cores for venting purposes, in fact with some cylindrical cores such as those required for cast pipes, it is customary to build the core up on a tube of this sort so that it serves as a backbone for the core as well as an effective conductor of gases. To make such a core, a perforated pipe of suitable dimensions is supported between a pair of trestles and tightly wound with coarse straw rope. This, besides being permeable to gases, provides a good surface for the application of the core sand or

loam and gives the core internal resilience necessary to accommodate contraction.

The lagged tube is then plastered with loam and rotated on the trestles against a template until the correct diameter and contour has been obtained.

Large bulky cores are vented by having a bed of coke or ashes rammed up in their interior. This porous cavity serves as a collecting chamber for the gases which are then led away through the print by a pipe or a continuous chain of coke.

Reinforcement.

Although the core sand mixture has a good strength in compression when baked, it has much less resistance to bending or torsion and slender cores subject to such stresses must be internally reinforced. This reinforcement, of course, is very helpful to the core in the green state and may be inserted primarily for that purpose.

Soft iron wires are placed within small cores to give them extra mechanical strength while larger cores are usually formed around cast iron grids which, besides stiffening the core, provide a point of attachment for lifting tackle.

The core wires are bent to shape by hand or formed on a jig and can be salvaged for re-use when the casting is cleaned out.

The grids are cast in open moulds struck out by the coremaker or a moulder and follow, in skeleton form, the outline of the core in one plane. Support in the other direction is obtained by pressing a tapered peg into the mould at intervals along the channels that are to form the grid, thus producing a series of prongs on the latter.

Mild steel loops for the attachment of crane hooks or other lifting tackle, may be cast into the grid or located around it later when the core is being formed. All metal reinforcement must be kept below the surface of the core so that any holes left for the connection of the hoist gear have to be filled in after the core has been finally placed in the mould. In most cases the grid has to be broken before it can be removed from the casting and is therefore seldom available for re-use, but the scrap metal can go back to the cupola for remelting.

The baking process takes from 1 to 8 hours, depending on the bulk of the core, and when this and any inspection or gauging has been carried out, a thin wash of special core paint is usually applied. This coating is made up from graphitic or talc compounds designed to reduce the possibility of the sand fusing on to the metal and to give the core a smoother surface finish.

Although coremaking is considered as secondary to moulding in the foundry, well-made cores are just as essential to the production of first-class castings as are good moulds and close attention must be paid to every stage of their manufacture.

The coremaker relies on the patternmaker for the boxes or templates from which he produces his cores, so that his skill as a tradesman is directed to the making of the special sand mixtures, their correct ramming, reinforcing, venting and baking to ensure that the shape of the core-box is reproduced exactly in the finished casting without adhesion to, or detrimental effects on, the metal.

Application of Cores.

In practice, some coring of the castings, Figs. 4, 6 and 8, would be expected, holes through the bosses to reduce the amount of machining being the most likely.

Such holes would be formed by lengths of the standard round core mentioned previously and to accommodate them, prints of similar diameter would be required on the patterns.

The prints are placed on the drag side of the mould and slightly tapered to assist the draw.

Moulding would proceed exactly as previously described, though a little more care would be required when the pattern was being withdrawn, due to the additional dragging surface presented. When the moulding had been completed a length of standard core, rubbed to a corresponding taper at one end, would be inserted in the impression left by the print.

To ensure that the core is central and securely located, a print may also be placed on the top side of the pattern, in which case the core is cut to the length gauged over the two prints and thus projects into the cope. For accurate work this extra stability is desirable, but as the cope mould must be lowered over the core without observation of what is happening being possible, many moulders prefer to work without top prints and instead cut the core slightly longer than the distance over the pattern and bottom print so that it is just nipped by the cope when the mould is closed. If the top box is raised again, the imprint of the core may be seen on the mould face and its position thus checked. When top prints are used they are made shorter and given more taper than those in the drag to assist moulding and give the core a better lead in. The average proportions of such prints are indicated in Fig. 6 (c).

It is a common practice to lighten the webs of solid pulleys with a series of circular holes and these could, if desired, be produced by baked cores, but as the web is comparatively thin and a generous taper may be given to the holes cut in the pattern, these would quite easily leave their own "cores" in the green sand. This procedure cannot normally be applied to the boss as the amount of taper required to mould a hole of this depth makes it impracticable.

Figs. 6 (b) and (c) include lightening holes in the pattern webs and the differences in taper due to the change in joint line position should be noted. In each case the hole must be smallest at the

parting and where the pattern is split through the web this makes for a better looking casting.

If for any reason it was decided to core the groove in the sheave pulley, Fig. 8, instead of moulding it completely in a three-part box, the pattern would appear as in Fig. 16 (a) and an annular core, as shown in its corebox, part view Fig. (b) would be placed in the recess left by the print.

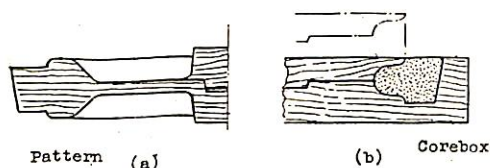


Fig. 16.

Where large annular cores of this sort are required they are usually made in a number of equal segments from one core box, the ring of segments being assembled in the mould.

The base holes in the bracket, Fig. 4, require special treatment if the useful flat back joint line is to be preserved, for it will be obvious that prints, the same shape as the holes required, be they elongated or round, if attached to the base of the pattern, would prevent it being withdrawn from the sand.

To overcome this, the prints must be carried up to the joint line as in Fig. 17. The pattern can now be moulded as described in the first example and plenty of taper is given to the sides of the tail prints, as they are called, so that they will not unduly increase the difficulty of withdrawing the deep flange of the bracket.

The corebox and core necessary for this type of print are shown in Fig. 11, and it will be seen that the bulk of the core is required to fill the recess left by the print and that the portion forming the hole in the casting is relatively small.

In placing the core, care must be taken to see that the inner face of the tail portion is flush with the mould, otherwise a recess or projection will be formed on the casting. Fig. 18 shows the core in position in the mould.

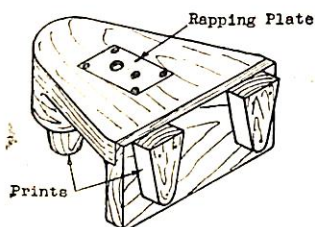


Fig. 17.

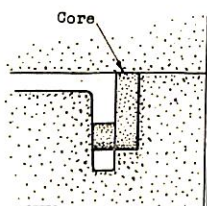


Fig. 18.

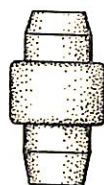


Fig. 19

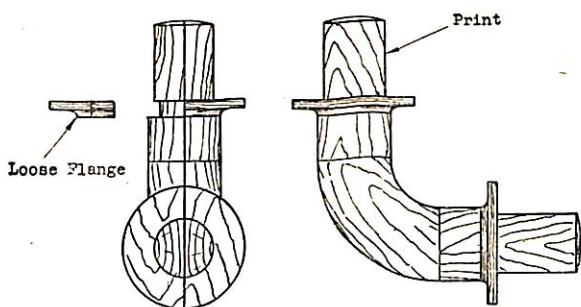


Fig. 20.

With very large pulleys or wheels it is often desirable to have the centre portion of the boss cored out to a diameter larger than that of the finished bore and this is quite easily accomplished with a core such as Fig. 19. The smaller diameters provide a machining allowance for the bore ends and the print portions are noticeable by reason of their taper.

The flanged pipe elbow is quite easily moulded if the pattern Fig. 20, is made in halves and the flanges are loose to enable them to be withdrawn separately after the main body of the pattern has been removed from the mould. The core also is easily made, but its perfect support in the mould is more difficult to obtain. It will be seen that the elbow of the core can only be supported through the end prints which are made longer to provide extra leverage for this, and for small castings the anchorage given in this way is usually sufficient to resist the floating action of the molten metal.

Larger cores must be restrained by chaplets at the elbow position, though a device sometimes adopted is to mould two elbows together in such a manner that one continuous core in the form of a broad U will pass through both and be supported in the middle, that is, the bottom of the U, as well as at the ends, and thus be sufficiently stable without chaplets.

Chaplets must be used in all places where the core has not sufficient anchorage or rigidity to retain its correct position or shape, but as they provide further problems for the moulder and leave unsightly marks on the casting it should be the aim of design to reduce the necessity for chaplets as far as possible.

Three common varieties of chaplets are shown in Fig. 15.

In jobbing foundry work, the use of cores to form undercut portions of a casting, is sometimes avoided by having what is known as a draw back in the mould or loose pieces on the pattern.

The former method is used only in pit or floor moulding, as a certain amount of free space is required to carry out the operation

and also because it is only justified where castings of a reasonable size are involved.

This core saving manoeuvre is accomplished by building the undercut portion of the mould upon a metal plate and dry-jointing it from the remainder so that eventually it may be drawn back to clear the pattern, before this is extracted. The mould is then restored by returning the drawback carefully to its original position and filling in behind.

Loose pieces, on the other hand, may be adopted on patterns of all sizes and they concern, in general, odd projections that prevent a pattern from being moulded in a simple manner.

Fig. 21 (a) shows a pattern, ideal for moulding in the drag with its flat back on the joint line, if it were not that bosses attached permanently to the web would make extraction from the mould impossible. If the bosses are only retained in position by loose pins, as shown in the illustration, the main pattern can be removed first, leaving room for the small facings to be withdrawn separately, as at (c).

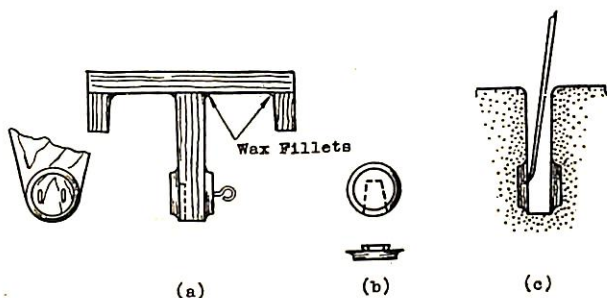


Fig. 21.

The moulder makes up the drag in the usual way on a turnover board with the loose pieces attached to the pattern and completes the mould up to and around the bosses before removing the pins. When filling in the last portion he must take care that the now loose bosses are not displaced, though this danger may be avoided if the more costly method of having them attached by a sliding dovetail, as in Fig. 21 (b), is adopted.

There are many applications of this method of drawing loose pieces back into the mould, to avoid the use of cores or a complicated joint line, but they are all dependent on there being sufficient space for this to be carried out.

They also require care in moulding and as wear takes place at the pins or dovetail, which must slide freely to start with, slight displacement of the loose pieces can occur.

SKELETON PATTERNS.

These, as the name suggests, are the bare bones of a pattern, used for the economy of patternmaking time and material, in the production of large "one off" type castings.

The smaller portions of the skeleton pattern may be solid, but the remainder consists of a series of ribs which indicate the shape and change of contour in profile form; the rib spacing depending largely on the rapidity of the change of section.

The pattern is usually made in halves with the jointing faces of solid 1" thick timber, and these act as the backbone from which the ribs of each half are sprung.

The moulder packs sand in between the ribs and smooths it off to their level, thus providing himself with the equivalent of a solid pattern. Cores, if simple, may be strickled in loam or made in a corebox in the usual way, but complicated cores are more economically and accurately made from the mould itself.

For this, the face of the mould is covered over with dried slab cores the exact depth of the wall thickness required in metal, and upon this facing the core, with its necessary grids and lifting irons is made. When dried sufficiently for strength, the core is removed and the mould restored to its original condition.

The heavy engineering and shipbuilding sections of the industry are the most common users of skeleton patterns and it is perhaps in this class of work, which frequently includes the use of drawbacks and loose pieces, that the moulder reaches the pinnacle of his creative skill.

LOAM MOULDING.

This is another type of moulding used for the production of large castings required in small quantities, where the cost of a complete pattern would be excessive.

Although there are many variations of loam moulding, it is confined in general to those shapes that may be generated by the revolution of a plane surface about an axis.

The loam that forms the inside face of the mould or core equivalent, is a high clay and moisture content sand mixture made to the consistency of a paste or slurry so that it may be plastered over a background of brickwork, built roughly to the shape required, and then dressed off to the correct dimensions.

The moulding equipment consists of a firmly anchored central pivot carrying a rotating arm to which may be attached the strickle or template. As the loam is built up, the strickle is rotated, its shaped edge dressing off the surplus slurry until the final diameters and heights have been obtained.

The only pattern equipment necessary is the strickle board and simple length gauges to check the diameters or any other dimensions not provided by the strickle itself.

PLATE MOULDING.

In the examples previously given, the moulding of one pattern only per box was considered, but it is quite feasible to include a number of patterns in one box provided that they are of a similar nature. The one down gate may still suffice, but in the drag mould this would branch off with one or more runners to each impression.

If several flat backed patterns were concerned the moulder would space them appropriately on the moulding board to suit the downgate position he has in mind and then proceed with the moulding operations as with one pattern. Should this series of castings be required a number of times, it is a logical step to have the patterns attached to the board in the positions found suitable and if holes to fit neatly over the drag box pins were provided in the moulding board, the patterns would always take up the same position relative to the box.

The board, or metal plate as it usually is in these cases, is made of uniform thickness so that when the drag has been rammed up and turned over, the cope box can be placed on the plain back of the moulding plate now uppermost and completed in the normal manner, except that the sand faces are separated by the thickness of the plate.

When the cope is removed the plate can be lifted away, withdrawing all the patterns simultaneously. The difficulty here is that the patterns cannot be rapped individually and as the plate is held by the box pins it should not be rapped sideways. The moulder does help withdrawal by tapping on the back of the plate before commencing to lift or by having an assistant to do this for him as he raises the plate or, again, a pneumatic vibrator may be fitted, but it will be seen that smooth, well-made patterns are essential for plate moulding.

When the patterns are withdrawn and the cope replaced, the sand faces come together so that as long as the plate is uniformly parallel its thickness is unimportant.

A further advance may be made by having a pattern for the complete runner also attached to the plate in the required position so that it is moulded integral with the patterns themselves. This produces consistent results as well as saving moulding time and a mark or spigot hole on the back of the plate over the runner position will show the moulder where to place the tube or down-stick to form the gate in the cope mould.

For quantity production of small castings it is usual to have several identical patterns in the one group or spray, but a variety of patterns may be mounted on one plate if they are required in equal quantities.

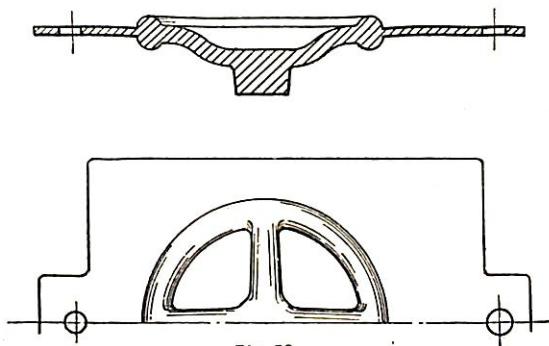
Where patterns normally requiring an oddside are to be moulded on a plate, the pattern must be split on the joint line and the cope

portion attached to the top side of the plate. This means that the two halves of the pattern are separated by the plate and must be accurately placed if the impressions are to match correctly when the half moulds are placed together.

To simplify or speed production in many cases, the half patterns are placed on separate plates so that copes and drags may be moulded simultaneously by different men or alternatively a series of drags made and then an equal number of copes.

With this system the half patterns must be located relative to the box pin holes in the respective plates, as these holes act as the connecting medium between the cope and drag. It will be seen that considerable care is needed in setting out the patterns if castings free from cross joints are to be produced, particularly where more than one pattern per plate is involved.

The above arrangements of mounting patterns on a flat plate can only be carried out where it is possible to have a straight joint line, but fortunately the majority of patterns required for plate moulding come in this category.



When it is desired to plate mould castings having an irregular parting line, it is necessary to cast the pattern into the plate itself, the latter sloping internally to the required joint but remaining flat at the perimeter to suit standard moulding boxes. Fig. 22 shows such a double-sided cast plate for a common dished hand-wheel and it will be seen that once the plate has been prepared, moulding can proceed on normal lines.

To obtain the cast plate, a master pattern, a replica of the wheel required, is moulded in the usual manner except of course, that special care is taken with the joint line and that the boxes are large enough to include the size of plate needed. When these moulds are completed, an open frame, the thickness and external shape of the pattern plate, is placed over the drag impression and sand is built up to the level of the frame between it and the moulding

box edges. With the skeleton frame removed and the cope mould replaced, the layer of sand built up separates the boxes and this, besides providing a space for the plate increases all the vertical dimensions through the subsequent cast pattern by a similar amount. This extra thickness disappears in the final moulding operations when two half-moulds produced from the pattern plate are placed together.

Single-sided cast plates may be produced in a like manner, although the desirability of lightening the pattern by coring out the back increases the difficulties.

MOULDING MACHINES.

Although the hand moulding of individual or grouped patterns mounted on plates, complete with runners, etc., increases the rate of mould production and permits the use of less highly skilled labour, most pattern plates are prepared for use on machines, which by reducing manual labour to a greater or lesser degree, increase the output of moulds per man still further.

One of the simplest forms of machine is essentially a moulding table with lever operated plungers for raising the mould off the pattern plate; all other operations being carried out as in hand-moulding. A development of this type of machine incorporates a pressure head to pack the mould by a squeezing action applied over the whole area of the box. The pressure plate may be brought down on to the mould or the latter may be raised against a fixed head, both motions being obtained by lever-operated cranks. In other types the squeezing action only is provided, the pattern withdrawal being carried out by hand.

Only simple moulds can be compacted correctly by compression alone, a little hand-ramming is frequently required in deeper parts of a mould that may be left soft by pressure uniformly applied to the whole surface. This disadvantage is overcome by more elaborate machines which have a jolting action as well as the pressure mechanism, both these functions being power operated. The jolting, which packs the lower region of the mould, but leaves the top loose, is followed by the squeezing motion to consolidate the mould in the reverse direction, and give the sand a uniform density.

The advantage of the single-sided pattern plates, described earlier, will now be apparent, for these can be screwed directly to the table of the machine and left there until the end of the production run. Where double-sided plates are used, a false frame must be placed between the plate and the machine table with the added disadvantage that the plate may deflect under the applied pressure.

A disadvantage common to the above machines is that the separation of the mould and the pattern plate has to be accomplished with the former uppermost, and as the sand is thus suspended

it is easily dislodged if the draw is at all difficult. Moulds having deep projections or cods are therefore most readily moulded on rollover or turnover machines as these are designed to enable the mould to be rotated through 190° so that the pattern can be withdrawn from the top.

Turnover machines may perform this function only or they may carry out the full sequence of moulding operations and be termed "turnover jolt squeeze pattern draw machines."

The sequence of operations for the production of a mould on such a machine is briefly, as follows :

A moulding box is placed over the pattern plate attached to the machine table and an open frame of predetermined depth is located on the upper edge of the box. Sand from an overhead hopper is directed into the box up to the level of the top of the frame, which is there simply to act as a gauge for the extra volume of loose sand required to pack the mould to the correct density. The table is then jolted several times after which the box is raised up against the solid pressure plate, for the squeezing motion.

With the box clamped firmly between the table and pressure head, the vertical C-shaped structure containing both these units is rotated on its central horizontal pivot through 180° , so that the pattern plate is now on top of the mould.

The return stroke of the machine table withdraws the pattern upwards from the mould, which, under its own weight, remains on the inverted pressure head. The operator then removes the finished mould, and a further rotation of the pivoted structure completes the cycle.

The coring up and closing of the mould is carried out further along the production line, so it will be seen that the moulder becomes in fact a machine operator only, and in fully-mechanised foundries where the sand and boxes are brought up and the completed moulds removed by conveyors, manual labour is reduced to a minimum.

The founding skill, of course, must go into the design of the pattern plate equipment and the preparation of suitable sand, but once these have been proved, routine control will ensure uniform results.

Compressed air is the most common means of motive power for moulding machines, particularly where the jolting action is involved, though there are many hydraulically-operated types and some activated by solenoids.

A machine well worthy of mention, although of a specialised type, is the sand slinger which, as its name might imply, is concerned only with the packing of the sand into the mould.

Sand, carried by bucket and band conveyors to a high-speed impeller at the end of an articulated arm, is slung into the moulding box with sufficient velocity to pack it to the correct hardness or density. The propulsion head is simply traversed up and down

until the box is filled, the equivalent to the ramming action being carried out at the same time and as the operating conditions remain constant, the mould is uniformly compacted throughout. This type of machine is most usefully employed where there is a considerable volume of sand to be handled in large boxes or where a rapid succession of smaller boxes may be deployed in its path.

PATTERNMAKING.

The patternshop may rightly be called the tool room of the foundry, and although the skilled moulder can, on occasion, produce quite remarkable results with only the rudiments of pattern equipment, good "tools" are essential for the economical production of industrial castings.

The modern tendency to specialization is progressively dividing the patternmaking craft into more sharply defined branches, and as the large increase in machine moulding has brought a corresponding demand for patterns that will retain their shape and accuracy after hundreds of operations in abrasive sand moulds, the metal patternmaker is playing an increasingly important part in foundry life. The wood patternmaker, however, still remains the basis of the industry and the principles applied to the construction of patterns for specialised castings are the same as those governing the general cases to be considered here.

As the sole purpose of a pattern is to produce moulds, its character is governed by foundry practice, with which the patternmaker must be familiar, but to translate the designers' ideas into tangible shape and form he must employ the principles of many other trades. The wood patternmaker uses the methods and tools of the joiner, the millwright, the wood-turner and carver respectively; he must be able to read drawings and set out complicated shapes in the solid and should possess some knowledge of machine shop practice, in fact, in few trades is the "know how" of so many others so essential to the perfection of one.

Wood is a natural patternmaking material, as it is easy to shape and fabricate, is light in weight for hand-moulding and is economically obtained. Although it suffers from a tendency to warp and shrink, these disadvantages can be mitigated by the correct selection of timbers and the skilful use of lamination or segmentation in their construction.

The woods used in patternmaking fall generally into two classes; one being the soft white or yellow pines and the other the mahogany species. Both of these timbers are very easily worked and when properly seasoned not unduly prone to shrinkage or distortion. The pines are soft and consequently lack strength, but for reasons of economy they must be used for the great majority of patterns, while the more expensive mahogany is reserved for the smaller or more delicate work, where its extra strength and durability show up to the greatest advantage.

Contraction.

Patterns must be made larger than the required casting to compensate for the contraction that takes place as the cast metal cools from its freezing point to atmospheric temperature.

The amount of contraction, too, varies with the specific metal, but the laborious process of calculating the allowance to be made on each dimension is avoided by the use of special rules which are graduated to include the necessary increase.

Twelve inches on a contraction rule, suitable for cast iron, therefore measure 12.1" on a standard rule, while the increase per foot for steel castings is about 0.2", and so on. If a metal pattern is to be made from a wooden master, two contractions have to be provided for on the latter; one to cover the shrinkage of the metal pattern itself and the other for the final casting in the normal way.

Setting Out.

Before a pattern is commenced, the method of moulding must be decided, for upon this the joints, if any, direction of tapers, provision for cores and construction generally depend.

This requires of the patternmaker the ability to visualise the casting in all its details from the drawing and when this is complicated he makes a full-scale layout, to contraction sizes, on a suitable board, this process enabling him to master any obscure details and to get a true sense of proportion of the job as a whole. On the layout the patternmaker can draw in the core prints, machining allowances or any special feature of pattern construction so that it forms a valuable source of reference during the pattern-making.

Jointing.

Jointing is carried out for the same reasons and in the same way as in cabinet-making or joinery, but as screws may be used in place of, or to reinforce, joints, irrespective of appearances, fancy jointing is not required in patternmaking. The joints should, however, be arranged to eliminate as far as possible, the exposure of end grain, particularly where dragging surfaces are concerned, for the roughening and swelling of end grain, due to its ready absorption of moisture from the mould, increases the difficulty of pattern withdrawal and the possibility of distortion.

Fig. 23 shows the building up of a pulley rim or the like from segments cut the long way of the grain and it will be seen that no actual end grain is exposed. This type of construction is widely used for circular or curved work as it has the other advantages of presenting uniform strength in all directions, eliminating distortion, making shrinkage uniform and saving timber.

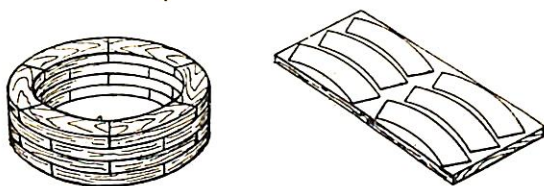


Fig. 23.

The segments are cut out with a bandsaw and for turned work the rings are built up on a lathe faceplate. In the first ring the segments are glued on the ends only and are attached to the faceplate by screws from behind. The face is then trued up in the lathe and another ring of segments built on, using glue and brads. The outer and inner diameters may be roughly turned at the same time to keep the diameters in check while the layers are being increased.

Further examples of jointing may be observed in the illustrations of patterns previously given and a method of fabricating to ease setting out and carving is shown in the core boxes, Figs. 11, 12 and 13.

In these cases, each portion involving a change in section, can be planed to the required thickness and the contour scribed out on each face. It is then a simple matter to cut out with a bandsaw and to pare through with a gouge or chisel for accuracy and smoothness, each portion being finished off completely before being assembled with its partners.

As the outside of a corebox is not restricted in size, the dimensions are made to suit the strength of the component parts and as reinforcing members may be added if necessary, good quality timber is not so essential as it is for patterns.

Taper.

The taper given to certain portions to assist moulding is an important feature of pattern construction and the direction in which it must be applied, as well as the advantage it confers, should be apparent from the few examples of moulding given.

The moulder, naturally likes all the taper he can get, but the patternmaker, who is responsible to other authorities for the accuracy of his work, must keep the taper within reasonable limits, particularly when he has to work from a drawing showing, more often than not, no taper at all.

The patternmaker from his general knowledge has a good idea where taper can be applied without detriment, and where it should be kept to a minimum; for example, he will appreciate that a good taper may be allowed on the boss and rib of the bracket,

Fig. 4, but that too much taper on the inner face of the base would prevent bolt heads from seating squarely and that if the outer face was not machined it would be required square with the web. If the base is to be machined, he will be able to put a reasonable taper on this face and save a little on the other, otherwise it must be restricted and kept on the inner face only.

Casting considerations apart, the taper to be allowed on any face is governed by conditions elsewhere in the pattern, so that each case must be treated on its merits.

Where one member having external faces only, projects into the drag, the taper may be at its minimum and an allowance of $\frac{1}{32}$ " per inch of depth would be made on each face, but if there were two such members, each makes the withdrawing of the other more difficult, and double the amount of taper may be necessary. Large internal holes apply for the same allowance, that is $\frac{1}{32}$ " per inch, but as the holes become smaller or the two portions of the pattern come closer together the strength of the cord of sand in between may be the deciding factor and more taper still must be provided, or this will break away.

Where portions of a solid pattern are moulded in the cope, about four times the amount of taper provided for similar drag parts should be allowed, but if the cope parts are loose they do not require special consideration as they can be rapped and withdrawn in the same way as drag patterns when the mould is opened.

Fillets.

Except where weak end grain would be presented, fillets are best worked in as an integral part of the pattern, but when the pattern is a built-up one, this involves a lot of hand carving and a considerable wastage of material, as all component members must be cut from timber of sufficient thickness to include the fillet. The common practice, therefore, is to construct the pattern with angular corners and to apply false fillets later.

Small fillets may be made in this way by pressing in strands of beeswax with a heated spherical-ended iron, while larger radii are provided by gluing in a strip of soft leather, bought specially shaped for the purpose. Both these methods have the advantage that they can be easily applied to curved surfaces, but they lack the permanence of wooden fillets which may be glued in on straight runs to form a more homogeneous part of the pattern.

Fig. 4 is an example of where fillets would be added after construction, but in most of the remaining examples the fillets would be turned from the solid as part of the shaping operation.

Dowels.

The dowels that are used to locate the halves of patterns or core boxes together must be accurately fitted to allow the portions to separate easily and yet permit no perceptible play between them.

Hardwood dowels fitting into plain drilled holes are commonly used, but as they are susceptible to dampness and wear, they do not give good service over long periods so that brass dowels and sockets are much to be preferred.

The brass fittings are made specially for the trade ; one type, shown in Fig. 13, is pressed from thin strip and retained in the wood by small screws, while another type is screwed for insertion in drilled holes.

Protection.

Wooden patterns are easily damaged by lifting spikes and rapping bars, even if care be taken by the moulder, so that patterns, which are to be used to any extent, should be fitted with metal inserts to take the strain of these operations. The metal plates, one of which is indicated in Fig. 17, should be as large as possible, and contain a tapped hole for the lifting screw, as well as a plain one for the rapping bar. Additional holes must be provided for countersunk head screws, to retain the plate when it is recessed into the pattern.

Figures.

Many castings are required with letters or figures cast upon them so these must either be placed on the pattern or impressed into the mould after the pattern has been withdrawn. The last procedure is adopted where the letters must come on a drawing surface or where they vary for each casting, and for this they are mounted on a thin wooden background of sufficient area to allow the letters or figures to be pressed into the mould without their support leaving an imprint itself.

Many sizes of lead or other soft metal letters are made for pattern requirements and they are distinguished by their well-tapered section which allows them to mould freely, even when attached to a slightly curved surface.

When the characters are to be placed permanently on the pattern, they may be fixed individually by varnish or fine brads, or the group may be mounted on a small strip and cast in a soft metal. The background of this panel is recessed into the pattern to give the same final result as individual type, but in a more robust fashion.

In either case the characters may be let into the pattern so that their top edge is flush with or below the surface.

Finish.

A good surface finish is essential if the pattern is to be drawn cleanly from the mould, without undue rapping, and with the better quality patterns, considerable attention is given to the smoothness

of the wood and to its protection from moisture, by the application of suitable varnishes.

When all constructional work has been completed, every external surface of the pattern is smoothed down with one or two grades of fine glass-paper. The soft nature of the woods employed obviates the need for coarse papers, unless they are used on sanding machines to eliminate a hand-planing operation on cheap work.

Screw heads or nail holes are filled with beeswax to make all surfaces level and smooth before the pattern is varnished.

Beeswax, it may be noted, is the patternmaker's equivalent of the draughtsman's eraser, and in a like manner the evidence of its use sometimes shows up at a later stage.

Shellac dissolved in spirit is considered the best coating for patterns and two to four coats of this can impart a smooth glossy finish resistant to moisture. Each coat is applied thinly and allowed to dry, and before the next coat is added the roughness due to the slight raising of the grain is removed with very fine or well used glass paper.

All inside faces are treated with clear shellac but distinctive colours are frequently added to the liquid used for outer surfaces. The main pattern is treated in one colour and the core prints are given a contrasting shade while machined faces, the position of chills, etc., may also be suitably indicated.

The colouring of the varnish gives a pleasing appearance to the pattern by providing uniformity to the varying timbers, fillets, wax filled holes, metal inserts or letters, and has the practical advantage of telling the moulder at a glance just what is involved.

FETTLING.

The casting as removed from the mould, is an unsightly object, with runners and risers still attached, cores with their internal wires or irons yet to be dislodged, and sand adhering to the surface generally. It is the responsibility of the fettling department to remove all these superfluous items and to make the casting presentable before it is despatched from the foundry.

Much manual labour is involved in the process, the tools of the trade being hammers, chisels, grinding wheels, saws, and wire brushes, with pneumatic chisels, shearing machines and band saws to give mechanical aid. Cleaning processes are speeded up with the use of rotary tumbling barrels, or shot blast machines, and in a few cases with high velocity water sluicing apparatus. The last mentioned is a comparatively new development having the advantages of speed and dust prevention but it is at the moment only applicable to the largest foundries as considerable capital outlay is involved.

The amount of fettling involved is naturally proportional to the bulk and intricacy of the object and is most difficult with steel castings due to the tough nature of the metal and the high casting temperatures involved. Iron castings on the other hand are in some ways easier to dress than the non-ferrous as the brittle nature of the first metal enables runners, joint flashes or other projections to be knocked off, where cutting would otherwise be required with the tougher non-ferrous castings.

Casting temperatures affect the fettler in so far as rougher surfaces are encountered, and the sand stripping becomes more difficult, as the casting temperature rises. The sand is most likely to adhere in confined or enclosed portions of a casting and thus increase the difficulty of fettling.

The draughtsman is not greatly concerned with fettling but he should recognize that it is necessary and can, on occasion, be made easier by changes in design.

DIE CASTING.

Before leaving the practical side of casting production a few words on the above important branch of the founding industry should be included although it has become almost a separate science and field of research.

The die casting process, in which a metal die replaces the sand mould, was first developed for low melting point alloys of zinc, lead, and tin bases, but as improved heat resisting metals have become available, dies having a favourable working life at higher temperatures, have enabled the economical production of aluminium alloy and brass castings.

There are two forms of die casting, depending on whether the die is filled under the action of gravity or by applied pressure, and the type and characteristics of the casting produced vary somewhat with each form.

In the first, the metal is poured into the die direct from a ladle and the casting solidifies under conditions similar to those obtaining in a sand mould, although of course, the rate of heat extraction is more rapid and troublesome gases are not evolved from the die. It is possible to incorporate risers and feeders in the mould so that liquid contraction can be provided for, and the size of the casting produced is limited only by the expense of the die, not by the capacity of the machine as in the pressure process.

The advantages of gravity die casting over its sand counterpart are, higher rate of output, much greater dimensional accuracy, better surface finish, and improved physical structure due to the finer grain size of the metal resulting from the more rapid cooling.

In pressure die casting the metal is injected into the die by compressed air acting directly on the melt or by a hydraulically

operated plunger, pressures of approximately 500 and 5,000-lb. per sq. inch being applied in the respective cases.

With these pressures it is possible to cast very thin sections of metal and to obtain a sharp definition of extremely fine details such as small lettering or screw threads, while the surface finish and accuracy provided makes machining unnecessary in most cases.

Still higher rates of output are possible as the modern die casting machine is almost fully mechanised, but the volume of metal it can handle and construction generally keep the casting within clearly defined dimensions for each size of machine.

As the applied pressure precludes the use of feeders open to the atmosphere, liquid shrinkage cannot be provided for, and in consequence the heavier sections of pressure die castings show internal porosity. Where the lighter pressures are used on lumpy castings this porosity can be visible to the naked eye on the examination of a fracture, but with higher pressures and thinner sections the porosity is of microscopic proportions only.

The high cost of the dies and the time in their manufacture are the most serious disadvantages of this casting process.

MACHINING ALLOWANCES.

As extra metal is required on the rough casting where machined faces occur, provision must be made for this on the pattern or in the core box. The amount of additional material allowed, depends primarily on the nature of the metal cast and the limits of pattern-making and moulding accuracy, but it will also be influenced by the possibility of surface unsoundness occurring within the area of the allowance.

Information with respect to machined faces must be conveyed to the patternmaker and the draughtsman has the choice of three lines of approach to this aspect of detailing.

The first and most common method is to leave the actual allowance for a machined face to the discretion of the patternmaker; the drawing in this case shows the finished casting dimensions, with the position of any machined faces indicated by a suitable symbol or colouring. This is a sound system for it leaves the responsibility in the hands of the craftsman, generally better acquainted with casting problems, and aware from the construction of his pattern, of the position that any machined face will occupy in the mould.

It will be found, however, that the patternmaker in his own interests will tend to be generous with machining allowances on the grounds that extra metal can always be taken off, but a face that fails to clean up may scrap the casting, with consequent repercussions in the patternshop. This point of view may prove

advantageous in many cases but it should be borne in mind in repetition work where extra machining and/or wasted metal would be expensive items.

On mass production work, however, it is usual to make a number of trial castings to determine, amongst other things, whether any adjustment to the machining allowance is necessary, before proceeding with production proper. Here again, it is worth noting that it is easier and more satisfactory to reduce an allowance on a pattern than to increase it.

The second method which may be adopted is to detail the finished casting as before but with the addition of dimensioned machining allowances indicated by full or dotted lines, shaded areas, etc. These additions will often increase the complexity of the drawing to a considerable extent.

To carry out this procedure successfully, the draughtsman needs to be well informed on foundry practice and be able to assess the method of moulding so that an extra allowance can be provided on faces where porous or dirty metal or shrinkage cavities are likely to occur. It is advisable therefore to indicate also the method of moulding, for a change in this will most certainly affect any special allowance provided, particularly where coring is involved.

An alternative way of specifying the allowance is to do it by means of a general note, which covers, in the simplest possible terms a sliding scale of allowances for various conditions. This machining specification may be included in the standard lettering of the casting detail sheets and will not, therefore, complicate the drawing in any way.

The third, and fortunately not common, method of detailing castings is to include the machining allowance in the overall dimensions, but not necessarily define its amount or location.

The draughtsman in this case makes the allowances, showing the casting as it is expected from the foundry, and preparing a separate drawing of the finished article, for use in the machine shop.

With this method the drawbacks of the preceding one are aggravated, as the patternmaker is not in a position to check back on the draughtsman and being relieved of all responsibility for allowances, cannot be expected to show further interest in them. The one advantage of this practice is that only the dimensions required for pattern construction are shown, with a resulting clarification of the drawing. The value of this to the patternmaker however, is more apparent than real for he has only to absorb the details on one occasion and the little extra time this takes when all the machining details are included, is more than compensated for by gains in other directions. The presence of machining tolerances, for instance, will, in the absence of other information, indicate at once the degree of accuracy likely to be

expected of unmachined dimensions and therefore the quality of pattern construction required.

It is in the machine shop, where repeated reference may be made to a drawing and where semi-skilled labour is more likely to be involved, that the advantage of a detail showing only the essentials for a particular operation, is most likely to be appreciated.

It is suggested that the practice of including all machining particulars on the patternmaker's drawing will produce the most satisfactory results in the majority of cases, and if the amount of the machining allowance is to be specified it should be done by indicating in a general rather than a particular sense, the average requirements for a given metal and type of machining. This allows the patternmaker discretionary powers in exceptional circumstances, for well versed in foundry lore though the draughtsman may be, it not infrequently happens that even a method of moulding advocated by the foundry man himself, fails in certain circumstances to produce a sound casting, and a procedure different from the normal has to be adopted before satisfaction is obtained.

As previously stated, the amount of metal allowed for machining may be divided into two parts; one depending on the type of metal and the other on the dimensional accuracy of the casting. The first will be constant for a class of metal but the second will increase roughly with the size of the machined face, its distance from other machined faces or datum points, and with the possibility of special inaccuracies, such as the displacement of cores. This second category of allowances can, apart from contraction differences, be considered as independent of the type of metal.

Ferrous metals, due to their carbon content, have the ability to harden considerably when cooled rapidly from high temperatures and as such chilling occurs when molten metal is poured into a mould, the skin of iron and steel castings is much more resistant to machining than the metal slightly below the surface.

Where the resistance to wear and abrasion is required, this hardening is an asset and it is frequently accentuated by the placing of metal "chills" in the mould to conduct the heat away more rapidly and thus increase the depth of the hardened skin.

The presence of sand grains fused on the surface of a casting is also detrimental to cutting tools, so where normal machining is to take place it is important from the point of tool life that the first cut off a ferrous casting is of sufficient depth to get below the outer skin. For this a margin of $\frac{1}{16}$ " over the finished size should always remain on the rough casting.

The common non-ferrous metals, such as the brasses and aluminium alloys, do not chill harden, and due to the lower casting temperatures, they are practically immune from fused sand additions so that the "type of metal" allowance can be limited to the removal of surface roughness for which $\frac{1}{32}$ " is usually ample.

The allowance necessary to cover dimensional inaccuracy must be based on a commonsense judgment of the difficulties involved in making the pattern to size and producing from it a mould of identical proportions. Many factors are involved in this, as will be considered in the next chapter, but in most cases their sum total can be covered adequately by a standard round figure allowance.

For non-ferrous work the total allowance is usually $\frac{1}{16}$ " per face, which means that cored holes are $\frac{1}{8}$ " smaller than the finished bore and $\frac{1}{8}$ " should also be allowed on faces cast at the top of the mould to ensure the removal of any dirty metal. Cast iron should carry double this allowance, with $\frac{1}{8}$ " per face as general, and $\frac{3}{16}$ " or $\frac{1}{4}$ " as the exceptional provision, for faces likely to act as collectors of impurities.

As steel presents greater casting difficulties a still more generous allowance is necessary, $\frac{3}{16}$ " being made the usual provision on normal faces while $\frac{1}{8}$ " is reserved for those most conveniently situated.

DIMENSIONAL ACCURACY.

The uncertainty relating to the dimensional accuracy of castings is a frequent source of worry to the draughtsman, for the extra proportions, clearance or machining, he must allow if a pessimistic view is taken, reduces the effectiveness of castings as machine parts, while an insufficient appreciation of the problem may lead to difficulties being encountered at a later stage.

It must be remembered that inaccuracy in castings is not inevitable but simply the result of economic circumstances, as the production of thousands of die castings to limits within plus or minus 0.003" will testify.

The institution of a system of tolerances on casting details will relieve the draughtsman of some responsibility, but if the limits are not reasonably proportioned, the cost of attaining them may well prove excessive, and ultimately lead to their total abandonment. It is therefore advisable to investigate the causes of errors, and the possibility of reducing them by design, or other means, not involving an increase in the cost of production.

The factors contributing to inaccuracy may best be examined progressively as they occur in the various stages of pattern making, moulding and casting. The discrepancies will vary widely with the class of casting and workmanship, but the figures tabulated at the end of the chapter are put forward as a fair average.

Patternmaking.

Pattern errors can be divided into those occurring in construction and those resulting from use or storage.

The accuracy obtained in manufacture is based on the ability to measure which in turn depends on the instruments used and

the complexity of the work piece. The metal patternmaker has at his disposal, the tools and gauges of the metal machinist, so that his work can be finished to precision engineering limits if required. This is providing that he is working from the solid or a cast pattern with a finishing allowance, for a cast metal pattern, simply smoothed down for moulding, will probably have greater inaccuracies than the wooden master pattern from which it was made.

Wood cannot be marked out or machined to the fine limits expected of metal and the greater degree of hand work involved makes the range of accuracy more variable. The wood patternmaker's stock gauges are rules and calipers and as these are similar to the instruments used by the draughtsman, the precision with which a full-sized drawing can be set out is a close guide to the accuracy obtaining in good quality wood patternmaking.

It must be borne in mind, however, that many dimensions on a pattern do not occur in a plane surface and that those dimensions obtained in a cumulative manner will have a cumulative error.

Newly-made patterns of the first quality should be accurate to within approximately plus or minus $\frac{1}{64}$ " on all dimensions that can be measured directly on a two foot steel rule, the smaller dimensions, such as thickness of flanges, being better than this figure and the larger overalls only slightly in excess.

When one or two castings only are required, the cost of patternmaking becomes proportionally large and may exceed the charges for moulding and metal if the best quality patterns are stipulated. It is a common practice, however, when there is little possibility of the castings being required again, to reduce the overall costs by allowing a cheaper form of pattern.

In this type, which for convenience will be termed second class, the accuracy as well as the quality of construction, will deteriorate, so that a limit of inaccuracy twice that of the first class patterns, should be allowed for.

A third class of pattern contains those made up in skeleton form and the sweeps or strickles used for striking up loam moulds. It is recognised that this type of pattern is used for cheapness where a reasonable dimensional latitude is permissible in the casting and this, together with the special moulding procedure, does not justify close attention to accuracy or finish. Strickles and the solid portions of skeleton patterns should be within the limits of second class work but double this tolerance should be prepared for on all other dimensions.

The changes taking place in wooden patterns after manufacture may be swelling or distortion in the mould due to the absorption of moisture, or shrinkage and warping in storage.

This group of inaccuracies will vary considerable with the class of pattern, being scarcely perceptible where the best woods and

methods of construction are used and most noticeable in the cheaper sorts of patterns.

The magnitude of the errors in each case will be proportional to the size of the pattern and will therefore be treated on a percentage basis.

The damage done to wooden patterns by careless handling and exposure to the weather must be treated as not happening in well conducted foundries.

Moulding.

The rapping of patterns to facilitate their withdrawal is probably the greatest single cause of error in moulding and although it may be negligible in machine moulding where pneumatic vibrators are used, it can reach considerable proportions in hand work on rough poorly tapered patterns.

Rapping always increases the volume of a casting, that is it increases the external dimensions and decreases internal ones, and this gain in bulk takes place in a horizontal direction, being greatest at the joint line. The smooth, well tapered and correctly jointed pattern shows the least variation due to rapping, the presence of taper being perhaps the most favourable feature.

Taking once again the bracket, Fig. 4, as an example and assuming that this is a well-made pattern of approximately 6" in overall height and width, the gain in size due to rapping will be in the order of $\frac{1}{32}$ " in each direction. The shallow pulley, Fig. 6, however, may only gain half this amount on a diameter of 6", the degree of rapping being more in proportion to the depth of the pattern than to its other dimensions.

Castings having large horizontal areas when cast can develop considerable vertical forces due to the head of metal in the down gates, and although the boxes may be secured firmly with clamps and weights, the tendency for the mould to be deflected or compressed remains. The pressure is equally to the sides of the mould but as these are more rigidly backed, the gain in size, if any, is most noticeable in the vertical directions, and is thus complementary to rapping rather than additive.

Portions of a mould not sufficiently compacted are also found out by the weight and pressure of the metal, and soft spots can, in this way, cause unwanted swellings on castings.

The use of cores introduces another possible source of error due to the chance of an inaccurate relationship between the core and the mould. With other than simple cores, great care is needed to obtain a perfect match between the core box and the pattern, for not only must the shapes allow for uniform wall thicknesses, etc., but their relationship with the prints must also be exact. Further discrepancies occurring are due, either to insufficient location of the core in the mould, or lack of strength in the core

itself, these weaknesses allowing a displacement to occur. The total errors can reach considerable proportions and where accuracy is important, gauging of the core and its position in the mould must be resorted to.

A further fault that becomes evident as a curious displacement of one part of the casting relative to the other is due, either to slackness at the dowels of a jointed pattern, or a similar fault at the moulding box pins. The former cause is the most likely as any movement at the dowels is magnified at the pattern edges whereas the relatively large centres of the box pins diminish the displacement at the pattern, and as it is the habit of the moulder to keep the cope box twisted in one direction against the drag, the possibility of error due to loose parts is still further reduced. Wooden patterns with wooden dowels soon wear and it is not unknown for moulders to use dowel holes for rapping in if the rapping holes are wrongly placed or non-existent.

A quick check on the pattern before it is used will eliminate this fault.

Casting.

The contraction rules used by the patternmaker should be regarded as suitable for average conditions only, as the amount of solid shrinkage taking place will vary with the analysis of the metal or alloy and also with the final chemical form of the alloying elements. The variation is due to the fluctuation of the freezing point and the change in volume accompanying a change in chemical form.

The difference in the contraction of cast iron and steel is a notable example as the doubling of the shrinkage for steel is mainly due to the fall in carbon content from around 3.5% for cast iron to less than 1.0% for steel. High duty cast irons with an intermediate carbon content have an intermediate rate of contraction while white cast irons shrink more than the grey varieties. These differences in the rate of contraction can be anticipated very closely by experienced foundrymen, but when the patterns are made by a separate concern, errors may arise from the patternmaker's lack of knowledge of the particular grade of metal to be cast.

These errors are, as a rule, slight; unless, due to a mistake, a pattern intended for steel or aluminium is made with a contraction allowance for cast iron or vice versa. In other cases co-operation between the patternmaker and foundryman is the best solution.

Table.

Pattern inaccuracies are impartially plus or minus, whereas errors arising in moulding show a tendency to be positive rather than negative. For the sake of simplicity this trend has been

ignored in the table and the figures given should be taken only as a guide to the accuracy of castings from normal patterns of dimensions up to 24 inches. For sizes larger than this the pattern error should be increased pro rata, but the moulding allowance only maintained or perhaps even reduced.

CASTING TOLERANCES.

Type of Pattern.	Patternmaking. Construction.	After.	Moulding. Total.	Total Error.
Machined Metal on Plate.	$\pm .005''$	Nil.	0.05%	$\pm (.005'' + .05\%)$
Cast Metal on Plate.	$\pm .015''$	Nil.	0.05%	$\pm (.015'' + .05\%)$
Cast Metal Hand Moulded.	$\pm .015''$	Nil.	0.1%	$\pm (.015'' + .1\%)$
1st Class Wood on Plate.	$\pm .015''$	0.05%	0.05%	$\pm (.015'' + .1\%)$
1st Class Wood Hand Moulded.	$\pm .015''$	0.1%	0.1%	$\pm (.015'' + .2\%)$
2nd Class Wood.	$\pm .03''$	0.15%	0.2%	$\pm (.03'' + .35\%)$
3rd Class Wood.	$\pm .07''$	0.2%	0.3%	$\pm (.07'' + .5\%)$

DESIGN.

Consideration given to foundry operations in the design of castings can have a beneficial effect, not only on production costs, but also on the quality of the metal and the accuracy of the cast object.

It is not often possible to modify an existing design, to facilitate production, without the sacrifice of some feature of operational efficiency or appearance, so that the best results are obtained if the foundry aspect is borne in mind as the design is developed.

The factors of cost, quality, and accuracy are to a considerable extent interdependent, and as will be obvious, the greatest improvement to all three will come from simplifications to design.

These changes may entail such variations as the substitution of two or three castings for one inevitably more complex, the reduction of coring, the elimination of loose pieces or difficult draws on patterns, or the adherence to simple geometrical shapes to assist pattern and corebox making.

The great advantage of casting over other methods of construction is the comparative ease with which intricate shapes can be produced, and the foundryman is therefore wise to meet the designer's increasing use of this characteristic. That the foundryman can rise to all occasions is abundantly evident but it is always as well to consider whether two castings, machined and bolted together, would not prove a sounder proposition both physically and economically.

A further advantage of castings is that the metal founded can be any one of a great number of alloys, each suited to its purpose

and provided at costs generally far lower than a possible substitute, while the surface finish and appearance are usually such as to require no further dressing than that normally carried out in the foundry.

The main adverse criticism is that untreated cast metal does not, under test, show such high values of strength, toughness or electrical conductivity, as forged, rolled or extruded metal of similar analysis. This slight inferiority in physical properties is usually due to the structure of the cast metal being less dense than that mechanically worked, though sometimes a failure under load may be attributed to the presence of residual stresses or even cracks caused by unfavourable casting conditions.

The density of a casting is reduced by the presence of cavities which may range in size from microscopic porosity to visible holes, such cavities being welded up when the metal is mechanically worked as in forging or rolling, etc.

Where unsoundness is the result of liquid shrinkage, or blow holes occasioned by inadequate venting, a change in design can have beneficial results, but where the porosity is due to the liberation of gases previously absorbed in the molten metal, only improvements in the melting and pouring practice will be effective.

In a like manner an alteration in design will have little effect on cracks or internal stresses induced by too rigid moulds or cores resisting the natural contraction of the metal, but where these phenomena are caused by a wide variation in the cooling rate throughout the casting, a modification to the design is the satisfactory remedy. If residual stresses only are involved, the introduction of "chills" and a variation in the running arrangements, may obviate the necessity for the additional expense of a stress relieving heat treatment, although this annealing is the safest practice and is to be recommended, in any case, where a high rate of loading is involved.

Soundness.

During the process of liquid shrinkage and solidification, heavy portions of a casting act as feeders to the adjacent lighter and therefore cooler sections, and unless further liquid metal is available to the thicker regions, shrinkage cavities will make their appearance. The moulder attacks this problem in two different ways; one being an endeavour to unify the temperature throughout the casting by placing heat conducting metal chills, or denseners as they are sometimes called, in the mould adjacent to the heavy sections, while the other method encourages the progressive solidification of the metal from the thinner to the thicker portions, the latter being connected to a riser or feeder which supplies compensating liquid metal as shrinkage takes place.

Both these methods increase foundry costs, and as they are not always 100% effective, the removal of the factors requiring their use is doubly welcome. For this reason uniformity of section or at least the avoidance of sudden changes in section is of the utmost importance in casting design.

Each local accumulation of metal should be regarded with disapproval and where marked variation in section thickness is unavoidable, every effort should be made to see that the heavy region is suitably placed for the application of a feeder, or failing this, that feeding can be carried out indirectly, through connecting portions of the casting. These points are not always easy to visualize from a drawing but a simple example of each may illustrate what is involved.

The apparently easy to cast flanged sleeve, Fig. 24 (a) is, in practice, extremely difficult to obtain free from porosity in the encircled region unless a feeding head, such as is shown at (b) is applied, and for positive results the dimension "w" must be greater than "d" to ensure that the feeder is the last to solidify. The removal of a similar feeder, placed directly over the region of possible trouble, encircled in Fig. 25 (a), would involve difficult machining, so that it is preferable to place the riser on the normally machined flange as in (b).

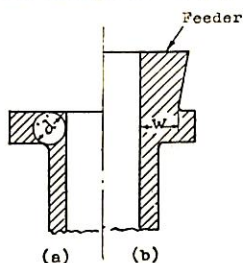


Fig. 24.

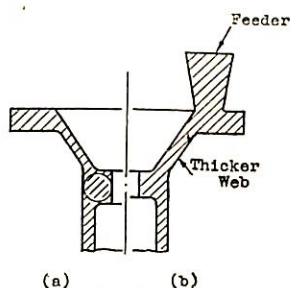


Fig. 25.

This would leave no blemish on the casting but it would only be effective if the web was thick enough to maintain liquid communication between the feeder and the heavy section below.

Feeding would be encouraged by top pouring the casting through the web so as thoroughly to heat the sand surrounding this and thus delay its cooling.

The ratio of section thickness in a casting should not exceed 2 : 1 and where this difference is approached the change in section should be made gradual by a taper as shown in Fig. 26.

Inner or enclosed portions should be thinner than the outer parts to balance the rate of cooling, the decrease in thickness of the wall less favourably situated for cooling being made on common-sense lines, perhaps in the ratio of 4 : 5.



Fig. 26.

To reduce local accumulations of metal, such methods as shown, Fig. 27, should be adopted whenever possible; the use of the maximum inscribed circle, attributed to Heuver, indicating the worst position and the degree in which it has been improved.

When examining the relative section thicknesses, the increase in dimensions due to machining allowances must be borne in mind as these, unfortunately more often than not aggravate the situation.

Thickness.

The actual thickness of metal that can be cast without difficulty, varies with the type of metal as well as with the distance it is obliged to travel across the mould, assuming of course that the casting temperature is constant and reasonably above the solidification point of each metal.

The high phosphorus content iron used in the light casting industry is very fluid and casts freely in sections only $\frac{1}{8}$ " thick, but the higher duty irons, including those intended for malleable castings, are more sluggish and for these $\frac{3}{16}$ " is a more desirable minimum.

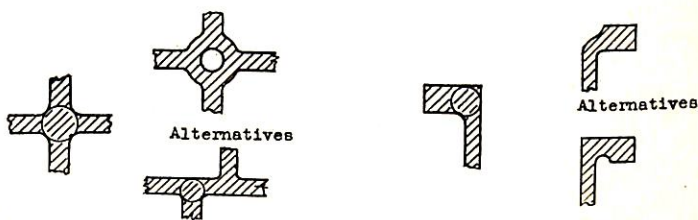


Fig. 27.

Steel, with its higher melting point and short range of fluidity, requires more generous treatment still and should not normally be expected in sections less than $\frac{1}{4}$ ".

Of the common non-ferrous metals the brasses are the most easily cast and run readily in walls $\frac{1}{8}$ " thick. The straight bronzes do not flow so well and therefore require a little more room for safety although the addition of small percentages of zinc or phosphorus improves their casting properties.

Pure molten aluminium, in oxidising conditions is always covered by a tenacious oxide film which reduces its flowing power considerably and for this reason sections thinner than $\frac{3}{16}$ " to $\frac{7}{32}$ "

are not recommended, but the improvement effected by the addition of copper or silicon, found in most modern aluminium alloys, enables quite large walls to be cast comfortably at $\frac{3}{16}$ " thick.

Residual Stress.

The steps taken to reduce variations in thickness will also alleviate the stresses and strains set up by the uneven cooling resulting from unequal section. Another means of stress relieving is the adoption of curved surfaces, a well-known example of which is the curve given to the arms of most thin rimmed cast pulleys. Curved members impart a greater degree of flexibility to the casting thus allowing it to adjust itself, without fracture, to the varying rates of cooling and contraction.

The higher rate of contraction of non-ferrous metals and their greater susceptibility to gas absorption make them more difficult to cast free from sinks, cavities or porosity, than cast iron, although their superior ductility frees them almost entirely from locked up stresses. Cast steel on the other hand, has a rigid nature and this, coupled with its high rate of contraction, makes it very prone to residual stress.

Camber.

Curvature or camber in a casting is the result of uneven cooling and it is the most noticeable on long castings having an unsymmetrical section of unequal thickness, though camber can occur through lack of symmetry only.

Fig. 28 (a) will be decidedly concave on the upper face, (b) being slightly curved in the same direction, while (c), even though of unequal section, will remain straight by reason of its perfect balance of symmetry.

The theory behind this quite common occurrence is that the massive member prevents the lighter and cooler section from contracting its full amount but, due to its greater strength, it is not restrained in a like manner when it, in turn, cools to normal temperatures. The concavity is therefore on the face that cools last and the amount if any, is proportional to the relative strengths of the members.

The larger area of metal in the web of Fig. 28 (b) is sufficient to draw the flanges if they are shallow, but a slight increase in their depth will give them enough strength to resist the curving

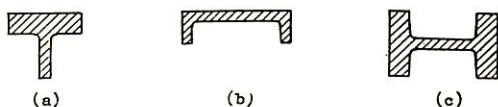


Fig. 28.

tendency. The same applies to (a), although the increase in depth would need to be considerably greater in this case.

Where camber is likely to occur, the patternmaker works a compensating curve on the pattern in the reverse direction, but as the amount of camber allowed can only be based on general empirical rules, trial and error may be necessary before a perfect correction is obtained. Apart from this the presence of a camber indicates that the casting is internally stressed, even if a correction has been made, and that later distortion may occur through ageing or the removal of a highly stressed skin by machining.

The designer should therefore strive for a casting of balanced proportions as well as one of uniform section.

Radii.

Radii are important factors in casting design, for besides contributing something to appearances, they have many practical advantages.

On all internal, and some external corners, they make moulding easier by assisting pattern withdrawal and eliminating the delicate sharp edges of sand. In casting they promote a smoother flow of metal in the mould and by beneficial influences during solidification, radii provide for a sounder and stronger product.

In castings subject to loading, radii are almost essential for the relief of stress concentration at corners, particularly when the load is an alternating one and may thus induce fatigue.

Discretion is required in their use however for the striking of too large a radius in a corner may increase the local mass of metal to the extent that it becomes a liability rather than an asset. Wherever possible an internal radius should be accompanied by an external one struck from the same centre.

A radius should not be put on the edge of a jointing face without good reason as in this position it will destroy the ideal simplicity of a flat joint. With such a radius the sand parting must lie on the centre of curvature and care is needed to obtain the correct line or the sand will be undercut on one face.

The difference in the joint lines of Figs. 5 and 9 illustrate this point. The addition of a radius to the back edge of Fig. 4 would involve extra moulding without any practical advantage, but in Fig. 8 the improvement given by the radius is worth the additional trouble.

The varieties of radii specified at the internal corners of any one casting should be kept to a minimum and those called for on castings as a whole are best limited to a few standard sizes.

This practice assists the pattern supplier by permitting the more frequent use of stock leather or wooden fillets, and it will be found that radii of $\frac{1}{8}$ ", $\frac{1}{4}$ ", $\frac{1}{2}$ ", $\frac{3}{4}$ " and 1" will suffice for all but very exceptional circumstances.

Cores.

The use of cores is unavoidable in many cases but where there is an alternative method of producing without their use it is usually to be preferred.

Ribbed instead of boxlike sections, the reversal of flanges to avoid undercutting, increased tapers or wider spacing of adjacent members may permit the pattern to provide the complete impression. Fig. 29 gives examples of how a slight alteration to the design can eliminate a core; (b) being the better alternative in each case.

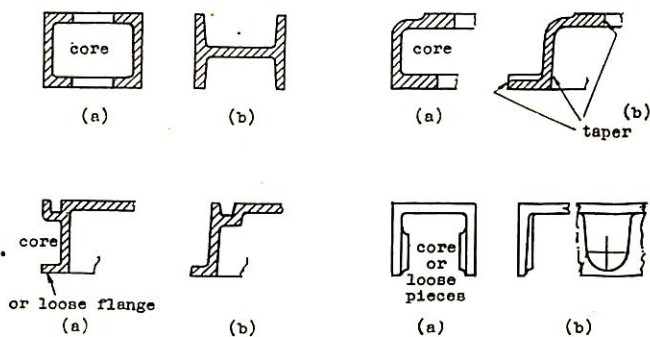


Fig. 29.

Besides involving extra labour, cores create further problems for the foundryman, and unless care is taken in their design and manufacture, faults will become apparent in the castings.

The most common troubles are due to misplaced or distorted cores giving rise to dimensional inaccuracies in otherwise sound castings. The remedy for this is to see that all cores, particularly where they must be placed in a horizontal position in the mould, are of adequate cross section for rigidity under casting conditions and that the locating points, that is the prints, are sufficient to anchor the core firmly in position. Two or three point location is always better than one and if the increased support and greater rigidity imparted, eliminate the use of chaplets, it is all the more advantageous.

The precautions to be taken to ensure that the core will collapse readily when it has fulfilled its purpose, are the responsibility of the coremaker.

Moulding is assisted if all print positions are situated in the drag box, for the core can then be inserted and gauged with the knowledge that it will not further be disturbed by the closing of the cope.

Blow holes or porosity in castings are often traceable to the inadequate venting of cores, and although the trouble, if observed,

may be cured by a change in foundry technique, prevention by improved design is more satisfactory.

Larger print areas provide greater facilities for venting the body of the core and the escape of gases is also greatly assisted if it is possible to provide an opening in a casting wall at what would be the blind end of a core.

Fig. 30 (a) shows a section through the mould for a bearing housing, the core of which can only be vented downwards, and as this is against the natural path of the gases, there is a strong tendency for them to try to escape through the metal, particularly if it is a light alloy. The original design specifies an oil hole at the side but if this can be replaced by a larger hole, suitable for a stauffer or grease nipple, as shown in Fig. 30 (b), a small core carrying a vent can be brought through to the cope and thus provide a much easier outlet for the gases.

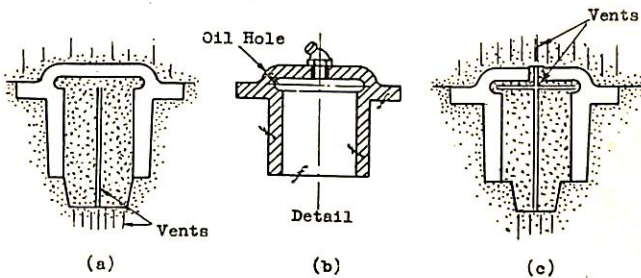


Fig. 30.

Besides assisting venting, larger openings in box like castings provide for more stable core prints and what is also quite important, they make easier the process of removing the cores and their reinforcing wires or grids. This fettling operation, which includes the cleaning of the inside of the casting, is not often considered in design and as the greater enclosure of a core by metal increases the possibility of sand fusing on to the casting, the conditions are worsened when the openings are small.

Taper.

The measures taken to reduce distortion or eliminate core displacement will automatically improve the accuracy of a casting and a further effective means to this end is to include taper wherever possible in the design.

As previously mentioned, the patternmaker must keep his tapers to a minimum, but the draughtsman, in full knowledge of the circumstances is able to make more generous allowances in

many cases and the reduction in rapping this will permit, enables the casting to finish more true to specified dimensions.

Further than this, the amount and distribution of the taper will be known when it is shown on the drawing, and its indication in good measure will enable the draughtsman to ask, with greater justification for closer tolerances in other directions.

The rates of taper given previously should be taken as the minimum and the greatest possible allowance consistent with reasonable uniformity of section should be specified.

For the average casting, taper apparent to the eye and dimensioned at the most important end, is usually of ample proportions and sufficiently indicated for the patternmaker's requirements, although a full specification leaves nothing to chance on important work.

Taper and other features of design should assist the moulding of machined surfaces face down and the small surface plate, Fig. 31, is an example of where moulding considerations must be sacrificed to those of casting.

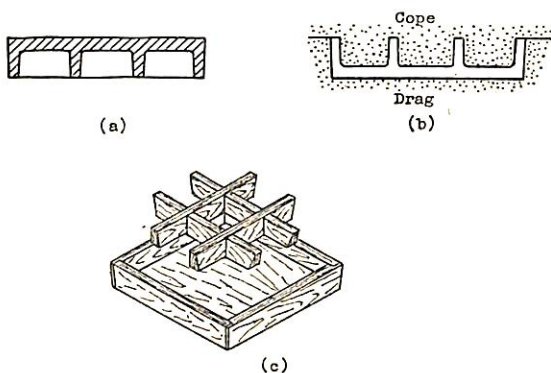


Fig. 31.

As is shown in Fig. 31 (a), the plate is most easily moulded in the drag with the flat top on the parting line between the boxes, and for this the taper on the sides and ribs should make these smaller at the bottom. It is, however, essential that the most dense metal is in the plane surface which means that this must take up the lowest possible position in the mould, with the joint line following instead the outline of the ribs, as indicated in (b).

For this direction of moulding the taper on the sides must be reversed and to assist the raising of the cope mould with its sus-

pended cods of sand, the ribs are left loose as in (c). With the pattern illustrated, the radius at the root of the ribs is formed by the moulder running his trowel around the edges of the upturned cope mould when the pattern has been removed.

Die Casting.

All the elements concerned in the design of sand moulded castings could be repeated with emphasis here, for instance the high cost of die manufacture makes simplicity more than important, it becomes an essential.

It must be remembered that the sand mould collapses to permit the extraction of the casting, the core too may be broken for dislodgement, but the die casting must be ejected from its mould with the absolute minimum number of joints allowable in the latter.

Oil sand cores are sometimes incorporated in gravity die castings but they are not applicable to pressure work and the difficulty of making metal cores that will collapse to permit withdrawal, will be appreciated.

Pressure die castings particularly, should be designed so that the mould will part at one plane face and contain the full impression, without undercuts or cores, in the two simple opposing halves. The parting line should, if possible, be arranged to occur at an edge, to allow the easy removal of any flash and to prevent it appearing on an otherwise smooth face.

Recessed features such as sunken lettering should be avoided, as they must project in the die and thus entail the machining away of the surrounding solid metal. It is far easier to provide raised lettering on the casting as this is simply engraved in the die face. For reasons explained earlier, heavy sections are subject to internal porosity and may prove to be a source of weakness rather than strength; uniformly thin sections are therefore more desirable. The greater accuracy of die castings allows the designer to reduce wall thicknesses much closer to the minimum required for functional strength and in the hydraulically operated pressure process this thickness is not limited by the machine as sections much thinner than normal requirements can be produced.

Whenever die casting is contemplated it is always advisable to obtain the opinion of a competent die maker before the design is finalised, for an apparently minor detail can sometimes make a considerable difference to the manufacturing costs of the die as well as the casting properties of the product.

Alterations to a die are seldom easy to carry out and often necessitate the remaking of an entire portion.

The co-operation of the patternmaker and foundryman is essential to the success of any casting design and this result will be more readily assured if the practical men are in possession of all the relevant data concerning the casting.

Such information would include :—

- (a) Nature of metal and any special properties or physical condition.
- (b) Working conditions, *i.e.*, shock, fatigue, temperature, corrosion, abrasion, gas or liquid pressure.
- (c) Degree of accuracy expected.
- (d) Relative importance of machined faces.
- (e) Possibility of further castings being required after initial order.

A title such as "C.I. Balance Weight" may in itself be a sufficient specification but the majority of castings deserve, and will benefit, from a more elaborate description.

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